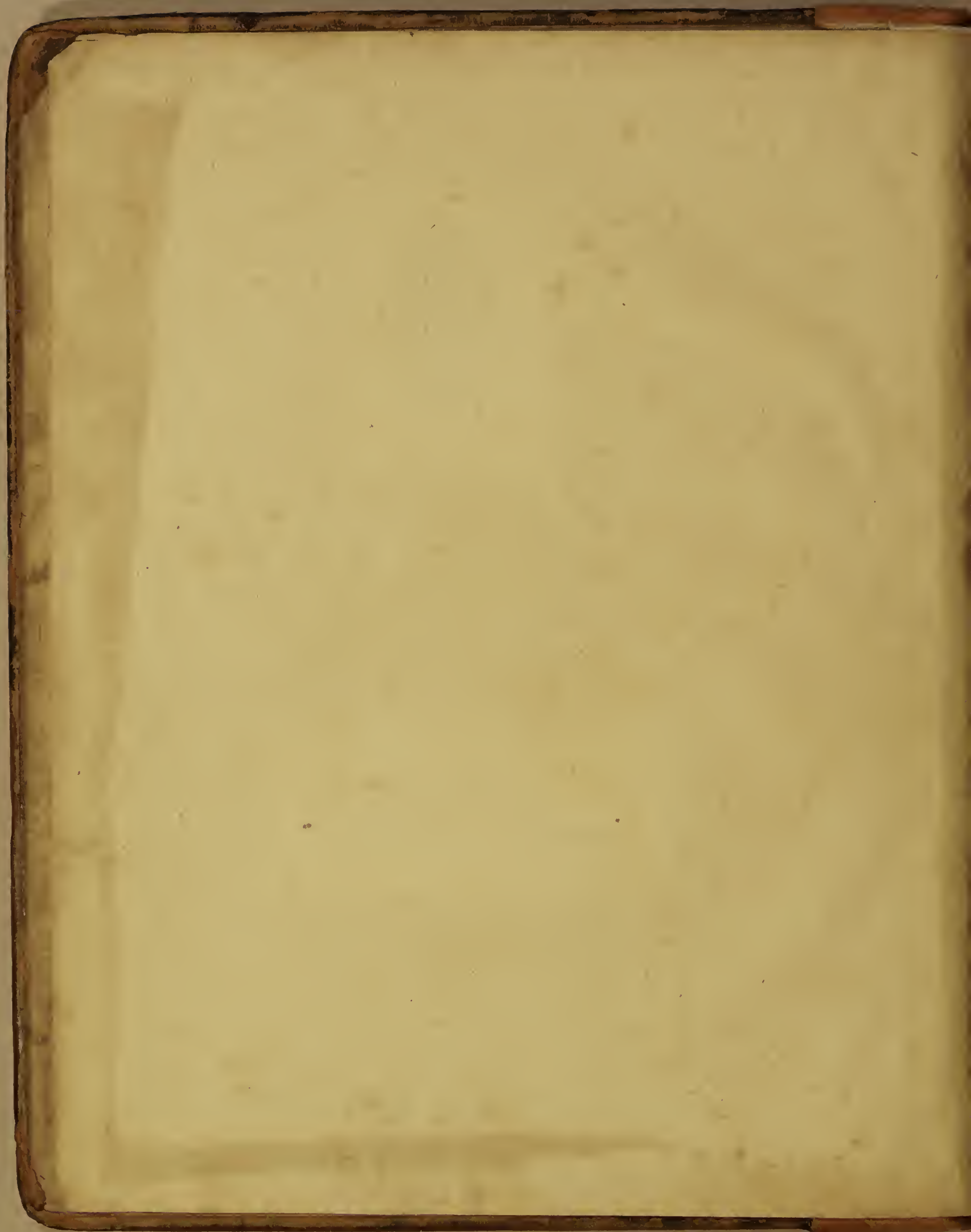


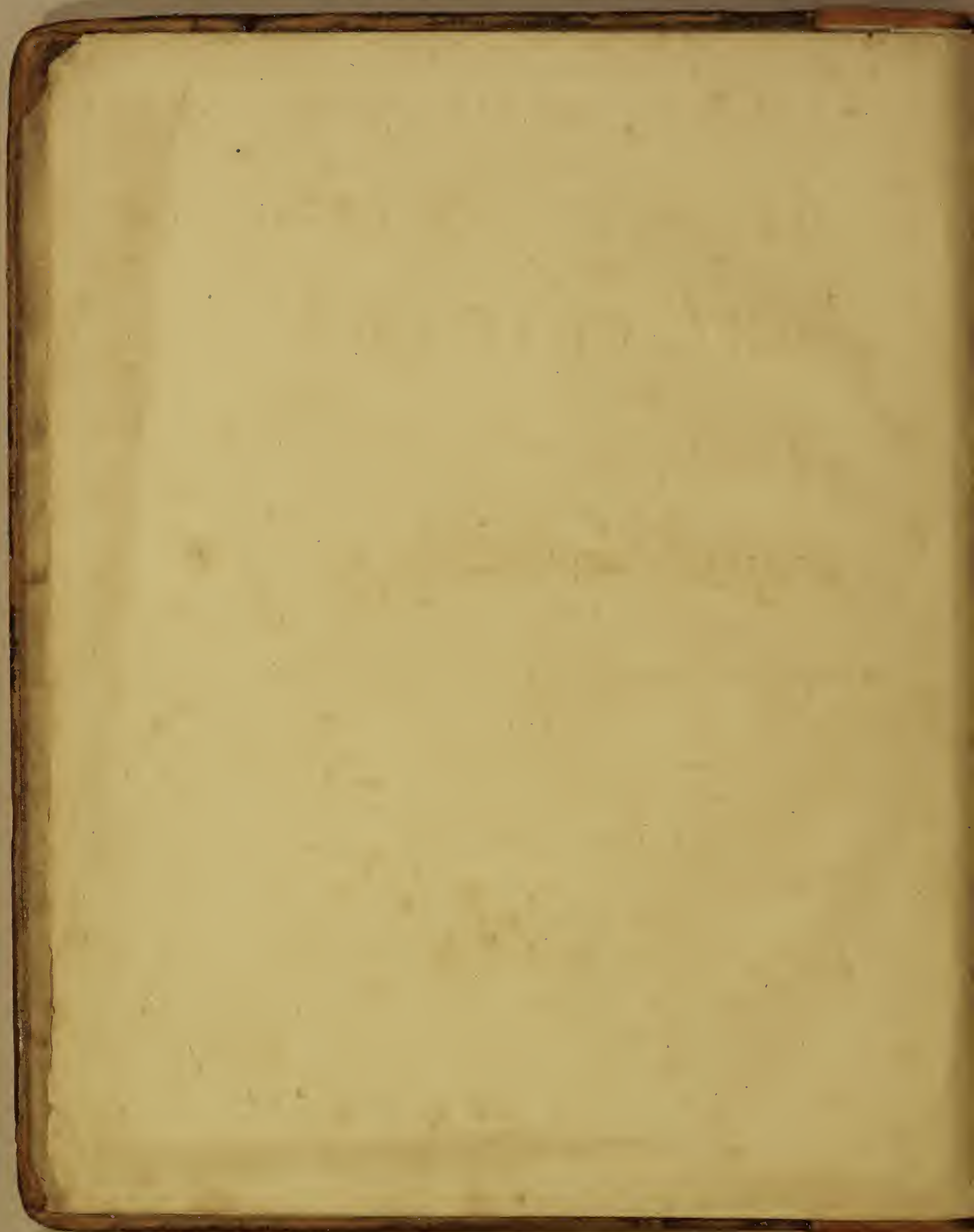


John Carter Brown
Library
Brown University

*The Gift of
The Associates of
The John Carter Brown Library*

J. Hatwell.
1755





NEW EXPERIMENTS
AND
OBSERVATIONS
ON
ELECTRICITY.

MADE AT

Philadelphia in America.

BY

BENJAMIN FRANKLIN, *Esq*;

AND

Communicated in several Letters to P. COLLINSON, *Esq*;
of London, F.R.S.

PART I.

The SECOND EDITION.

L O N D O N:

Printed and fold by D. HENRY, and R. CAVE, at *St*
John's-Gate. 1754. (Price 2s 6d.)

THE
COLLECTION
OF
THE
LIBRARY
OF THE
MUSEUM OF
NATURAL HISTORY
OF THE
CITY OF
NEW YORK

THE
COLLECTION
OF
THE
LIBRARY
OF THE
MUSEUM OF
NATURAL HISTORY
OF THE
CITY OF
NEW YORK

THE
COLLECTION
OF
THE
LIBRARY
OF THE
MUSEUM OF
NATURAL HISTORY
OF THE
CITY OF
NEW YORK

THE
COLLECTION
OF
THE
LIBRARY
OF THE
MUSEUM OF
NATURAL HISTORY
OF THE
CITY OF
NEW YORK

RPJC



LETTER I.

FROM

Mr BENJ. FRANKLIN, of *Philadelphia*,

TO

Mr PETER COLLINSON, F.R.S. *London*.

S I R,

July 28, 1747.



THE necessary trouble of copying long letters, which perhaps when they come to your hands may contain nothing new, or worth your reading (so quick is the progress made with you in Electricity) half discourages me from writing any more on that subject. Yet I cannot forbear adding a few observations on M. *Muschenbroek*'s wonderful bottle.

B

i. The

1. The non-electric contain'd in the bottle differs when electrified from a non-electric electrified out of the bottle, in this: that the electrical fire of the latter is accumulated *on its surface*, and forms an electrical atmosphere round it of considerable extent; but the electrical fire is crowded *into the substance* of the former, the glass confining it.

2. At the same time that the wire and top of the bottle, &c. is electrified *positively* or *plus*, the bottom of the bottle is electrified *negatively* or *minus*, in exact proportion: *i. e.* whatever quantity of electrical fire is thrown in at top, an equal quantity goes out of the bottom. To understand this; suppose the common quantity of Electricity in each part of the bottle, before the operation begins, is equal to 20; and at every stroke of the tube, suppose a quantity equal to 1 is thrown in; then, after the first stroke, the quantity contain'd in the wire and upper part of the bottle will be 21, in the bottom 19. After the second, the upper part will have 22, the lower 18, and so on 'till after 20 strokes, the upper part will have a quantity of electrical fire equal to 40, the lower part none: and then the operation ends: for no more can be thrown into the upper part, when no more can be driven out of the lower part. If you attempt to throw more in, it is spued back thro' the wire, or flies out in loud cracks thro' the sides of bottle.

3. The equilibrium cannot be restored in the bottle by *inward* communication or contact of the parts; but it must be done by a communication form'd *without* the bottle,

tle, between the top and bottom, by some non-electric, touching both at the same time ; in which case it is restored with a violence and quickness inexpressible : or, touching each alternately, in which case the equilibrium is restored by degrees.

4. As no more electrical fire can be thrown into the top of the bottle, when all is driven out of the bottom, so in a bottle not yet electrified, none can be thrown into the top, when none *can* get out at the bottom ; which happens either when the bottom is too thick, or when the bottle is placed on an electric *per se*. Again, when the bottle is electrified, but little of the electrical fire can be *drawn out* from the top, by touching the wire, unless an equal quantity can at the same time *get in* at the bottom. Thus, place an electrified bottle on clean glass or dry wax, and you will not, by touching the wire, get out the fire from the top. Place it on an non-electric, and touch the wire, you will get it out in a short time ; but soonest when you form a direct communication as above.

So wonderfully are these two states of Electricity, the *plus* and *minus*, combined and balanced in this miraculous bottle ! situated and related to each other in a manner that I can by no means comprehend ! If it were possible that a bottle should in one part contain a quantity of air strongly compressed, and in another part a perfect vacuum, we know the equilibrium would be instantly restored *within*. But here we have a bottle containing at the same time, a *plenum* of electrical fire, and a *vacuum* of the same fire ; and yet

the equilibrium cannot be restored between them but by a communication *without*! though the *plenum* presses violently to expand, and the hungry vacuum seems to attract as violently in order to be filled.

5. The shock to the nerves (or convulsion rather) is occasion'd by the sudden passing of the fire through the body in its way from the top to the bottom of the bottle. The fire takes the shortest course, as Mr *Watson* justly observes: But it does not appear, from experiment, that, in order for a person to be shocked, a communication with the floor is necessary; for he that holds the bottle with one hand, and touches the wire with the other, will be shock'd as much, though his shoes be dry, or even standing on wax, as otherwise. And on the touch of the wire (or of the gun-barrel, which is the same thing) the fire does not proceed from the touching finger to the wire, as is supposed, but from the wire to the finger, and passes through the body to the other hand, and so into the bottom of the bottle.

EXPERIMENTS *confirming the above.*

EXPERIMENT I.

Place an electrized phial on wax; a small cork-ball suspended by a dry silk-thread held in your hand, and brought near to the wire, will first be attracted, and then repelled: when in this state of repellency, sink your hand, that the ball may be brought towards the bottom of
the

the bottle; it will there be instantly and strongly attracted, 'till it has parted with its fire.

If the bottle had an electrified atmosphere, as well as the wire, an electrified cork would be repelled from one as well as from the other.

EXPERIMENT II.

FIG. I. From a bent wire (*a*) sticking in the table, let a small linnen thread (*b*) hang down within half an inch of the electrified phial (*c*). Touch the wire of the phial repeatedly with your finger, and at every touch you will see the thread instantly attracted by the bottle. (This is best done by a vinegar cruet, or some such belly'd bottle). As soon as you draw any fire out from the upper part by touching the wire, the lower part of the bottle draws an equal quantity in by the thread.

EXPERIMENT III.

FIG. 2. Fix a wire in the lead, with which the bottom of the bottle is armed, (*d*) so as that bending upwards, its ring-end may be level with the top or ring-end of the wire in the cork (*e*), and at three or four inches distance. Then electrify the bottle, and place it on wax. If a cork suspended by a silk thread (*f*) hang between these two wires, it will play incessantly from one to the other, 'till the bottle is no longer electrified; that is, it fetches and carries fire from the top to the bottom of the bottle, 'till the equilibrium is restored.

E X-

E X P E R I M E N T IV.

FIG. 3. Place an electricised phial on wax; take a wire (*g*) in in form of a *C*, the ends at such a distance when bent, as that the upper may touch the wire of the bottle, when the lower touches the bottom: stick the outer part of a stick of sealing wax (*b*) which will serve as a handle. Then apply the lower end to the bottom of the bottle, and gradually bring the upper-end near the wire in the cork. The consequence is, spark follows spark till the equilibrium is restored. Touch the top first, and on approaching the bottom with the other end, you have a constant stream of fire, from the wire entering the bottle. Touch the top and bottom together, and the equilibrium will soon be restored, but silently and imperceptibly; the crooked wire forming the communication.

E X P E R I M E N T V.

FIG. 4. Let a ring of thin lead or paper surround a bottle (*i*), even at some distance from or above the bottom. From that ring let a wire proceed up, 'till it touch the wire of the cork (*k*). A bottle so fixt cannot by any means be electricised: the equilibrium is never destroyed: for while the communication between the upper and lower parts of the bottle is continued by the outside wire, the fire only circulates: what is driven out at bottom, is constantly supply'd from the top. Hence a bottle cannot be electricised that is foul or moist on the outside.

E X-

E X P E R I M E N T VI.

Place a man on a cake of wax, and present him the wire of the electrified phial to touch, you standing on the floor, and holding it in your hand. As often as he touches it, he will be electrified *plus*; and any one standing on the floor may draw a spark from him. The fire in this experiment passes out of the wire into him; and at the same time out of your hand into the bottom of the bottle.

E X P E R I M E N T VII.

Give him the electrical phial to hold; and do you touch the wire; as often as you touch it he will be electrified *minus*, and may draw a spark from any one standing on the floor. The fire now passes from the wire to you, and from him into the bottom of the bottle.

E X P E R I M E N T VIII.

Lay two books on two glasses, back towards back, two or three inches distant, Set the electrified phial on one, and then touch the wire; that book will be electrified *minus*; the electrical fire being drawn out of it by the bottom of the bottle. Take off the bottle, and holding it in your hand, touch the other with the wire; that book will be electrified *plus*; the fire passing into it from the wire, and the bottle at the same time supply'd from your hand. A suspended small cork-ball will play between these books till the equilibrium is restored.

E X-

E X P E R I M E N T IX.

When a body is electrified *plus* it will repel an electrified feather or small cork-ball. When *minus* (or when in the common state) it will attract them, but stronger when *minus* than when in the common state, the difference being greater.

E X P E R I M E N T X.

Tho', as in EXPER. VI. a man standing on wax may be electrified a number of times, by repeatedly touching the wire of an electrified bottle (held in the hand of one standing on the floor) he receiving the fire from the wire each time: yet holding it in his own hand, and touching the wire, tho' he draws a strong spark, and is violently shock'd, no Electricity remains in him; the fire only passing thro' him from the upper to the lower part of the bottle. Observe, before the shock, to let some one on the floor touch him to restore the equilibrium in his body; for in taking hold of the bottom of the bottle, he sometimes becomes a little electrified *minus*, which will continue after the shock; as would also any *plus* Electricity, which he might have given him before the shock. For, restoring the equilibrium in the bottle does not at all effect the Electricity in the man thro' whom the fire passes; that Electricity is neither increased nor diminish'd.

E X P E R I M E N T XI.

The passing of the electrical fire from the upper to the lower part of the bottle, to restore the equilibrium is render'd strongly visible by the following pretty experiment

ment. Take a book whose cover is filletted with gold; bend a wire of eight or ten inches long in the form of (*m*) Fig. 5. slip it on the end of the cover of the book over the gold line, so as that the shoulder of it may press upon one end of the gold line, the ring up, but leaning towards the other end of the book. Lay the book on a glass or wax; and on the other end of the gold lines, set the bottle electrified: then bend the springing wire, by pressing it with a stick of wax till its ring approaches the ring of the bottle wire; instantly there is a strong spark and stroke, and the whole line of gold, which completes the communication between the top and bottom of the bottle, will appear a vivid flame, like the sharpest lightning. The closer the contact between the shoulder of the wire, and the gold at one end of the line, and between the bottom of the bottle and the gold at the other end, the better the experiment succeeds. The room should be darkened. If you would have the whole filletting round the cover appear in fire at once, let the bottle and wire touch the gold in the diagonally opposite corners.

I am, &c.

B. FRANKLIN.

C

LET-

LETTER II.

FROM

Mr BENJAMIN FRANKLIN, of *Philadelphia*,

TO

Mr PETER COLLINSON, F.R.S. *London*.

S I R,

Sept. 1, 1747.

IN my last I informed you that, in pursuing our electrical enquiries, we had observed some particular Phænomena, which we looked upon to be new, and of which I promised to give you some account, tho' I apprehended they might possibly not be new to you, as so many hands are daily employ'd in electrical experiments on your side the water, some or other of which would probably hit on the same observations.

The first is the wonderful effect of pointed bodies, both in *drawing off* and *throwing off* the electrical fire. For example:

Place an iron shot of three or four inches diameter, on the mouth of a clean dry glass bottle. By a fine silken thread from the ceiling, right over the mouth of the bottle, suspend a small cork-ball, about the bigness of a marble; the
thread

thread of such a length, as that the cork-ball may rest against the side of the shot. Electrify the shot, and the ball will be repelled to the distance of four or five inches, more or less, according to the quantity of Electricity.— When in this state, if you present to the shot the point of a long slender sharp bodkin, at six or eight inches distance, the repellency is instantly destroy'd, and the cork flies to the shot. A blunt body must be brought within an inch, and draw a spark, to produce the same effect. To prove that the electrical fire is *drawn off* by the point, if you take the blade of the bodkin out of the wooden handle, and fix it in a stick of sealing wax, and then present it at the distance aforesaid, or if you bring it very near, no such effect follows; but sliding one finger along the wax till you touch the blade, and the ball flies to the shot immediately.— If you present the point in the dark, you will see, sometimes at a foot distance, and more, a light gather upon it like that of a fire-fly or glow-worm; the less sharp the point, the nearer you must bring it to observe the light; and at whatever distance you see the light, you may draw off the electrical fire, and destroy the repellency.— If a cork-ball so suspended be repelled by the tube, and a point be presented quick to it, tho' at a considerable distance, 'tis surprising to see how suddenly it flies back to the tube. Points of wood will do as well as those of iron, provided the wood is not dry; for perfectly dry wood will no more conduct Electricity than sealing wax.

To shew that points will *throw off* as well as *draw off* the electrical fire; lay a long sharp needle upon the shot, and you cannot electrify the shot, so as to make it repel the cork-ball.—Or fix a needle to the end of a suspended gun-barrel, or iron rod, so as to point beyond it like a little bayonet; and while it remains there, the gun-barrel, or rod, cannot by applying the tube to the other end be electrified so as to give a spark, the fire continually running out silently at the point. In the dark you may see it make the same appearance as it does in the case beforementioned.

The repellency between the cork-ball and the shot is likewise destroy'd. 1. By sifting fine sand on it; this does it gradually. 2. By breathing on it. 3. By making a smoke about it from burning wood.* 4. By candle light, even tho' the candle is at a foot distance: these do it suddenly.—The light of a bright coal from a wood fire; and the light of red-hot iron do it likewise; but not at so great a distance. Smoke from dry rosin dropt on hot iron, does not destroy the repellency; but is attracted by both shot and cork-ball, forming proportionable atmospheres round them, making them look beautifully, somewhat like some of the figures in *Burnet's* or *Whiston's* theory of the earth.

* We suppose every particle of sand, moisture, or smoke, being first attracted and then repelled, carries off with it a portion of the electrical fire; but that the same still subsists in those particles, till they communicate it to something else; and that it is never really destroyed.—So when water is thrown on common fire, we do not imagine the element is thereby destroyed or annihilated, but only dispersed, each particle of water carrying off in vapour its portion of the fire, which it had attracted and attached to itself.

N.B. This

N. B. This experiment should be made in a closet where the air is very still.

The light of the sun thrown strongly on both cork and shot by a looking-glass for a long time together, does not impair the repellency in the least. This difference between fire-light and sun-light, is another thing that seems new and extraordinary to us.

We had for some time been of opinion, that the electrical fire was not created by friction, but collected, being really an element diffus'd among, and attracted by other matter, particularly by water and metals. We had even discovered and demonstrated its afflux to the electrical sphere, as well as its efflux, by means of little light wind-mill wheels made of stiff paper vanes, fixed obliquely and turning freely on fine wire axes. Also by little wheels of the same matter, but formed like water wheels. Of the disposition and application of which wheels, and the various phænomena resulting, I could, if I had time, fill you a sheet. The impossibility of electrifying one's self (tho' standing on wax) by rubbing the tube and drawing the fire from it; and the manner of doing it by passing the tube near a person or thing standing on the floor, &c. had also occurred to us some months before Mr *Watson's* ingenious *Sequel* came to hand, and these were some of the new things I intended to have communicated to you.—But now I need only mention some particulars not hinted in that piece, with our reasonings thereupon; though perhaps the latter might well enough be spared.

1. A per-

1. A person standing on wax, and rubbing the tube, and another person on wax drawing the fire; they will both of them, (provided they do not stand so as to touch one another) appear to be electrified, to a person standing on the floor; that is, he will perceive a spark on approaching each of them with his knuckle.

2. But if the persons on wax touch one another during the exciting of the tube, neither of them will appear to be electrified.

3. If they touch one another after exciting the tube, and drawing the fire as aforesaid, there will be a stronger spark between them, than was between either of them and the person on the floor.

4. After such strong spark, neither of them discover any electricity.

These appearances we attempt to account for thus. We suppose, as aforesaid, that electrical fire is a common element, of which every one of the three persons abovementioned has his equal share, before any operation is begun with the tube. *A*, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately supply'd. *B*, (who stands on wax likewise) passing his knuckle along near the tube, receives the fire which was collected by the glass from *A*; and his communication with the common stock being likewise cut off, he retains the additional quantity received.—To *C*, standing on the floor, both appear to be

be electrified: for he having only the middle quantity of electrical fire, receives a spark upon approaching *B*, who has an over quantity; but gives one to *A*, who has an under quantity. If *A* and *B* approach to touch each other, the spark is stronger, because the difference between them is greater; after such touch there is no spark between either of them and *C*, because the electrical fire in all is reduced to the original equality. If they touch while electrifying, the equality is never destroy'd, the fire only circulating. Hence have arisen some new terms among us: we say, *B*, (and bodies like circumstanced) is electrified *positively*; *A*, *negatively*. Or rather, *B* is electrified *plus*; *A*, *minus*. And we daily in our experiments electrify bodies *plus* or *minus* as we think proper.—To electrify *plus* or *minus*, no more needs to be known than this, that the parts of the tube or sphere that are rubbed, do, in the instant of the friction attract the electrical fire, and therefore take it from the thing rubbing: the same parts immediately, as the friction upon them ceases, are disposed to give the fire they have received, to any body that has less. Thus you may circulate it, as Mr *Watson* has shewn; you may also accumulate or subtract it upon or from any body, as you connect that body with the rubber or with the receiver, the communication with the common stock being cut off. We think that ingenious gentleman was deceived, when he imagined (in his *Sequel*) that the electrical fire came down the wire from the ceiling to the gun-barrel, thence to the sphere, and so electrified the machine
and

and the man turning the wheel, &c. We suppose it was *driven off*, and not brought on through that wire; and that the machine and man, &c. were electrified *minus*; *i. e.* had less electrical fire in them than things in common.

As the vessel is just upon sailing, I cannot give you so large an account of American Electricity as I intended: I shall only mention a few particulars more.—We find granulated lead better to fill the phial with, than water, being easily warmed, and keeping warm and dry in damp air.—We fire spirits with the wire of the phial.—We light candles, just blown out, by drawing a spark among the smoke between the wire and snuffers.—We represent lightning, by passing the wire in the dark over a china plate that has gilt flowers, or applying it to gilt frames of looking-glasses, &c.—We electrify a person twenty or more times running, with a touch of the finger on the wire, thus: He stands on wax. Give him the electrified bottle in his hand. Touch the wire with your finger, and then touch his hand or face; there are sparks every time.—We encrease the force of the electrical kiss vastly, thus: Let *A* and *B* stand on wax; give one of them the electrified phial in hand; let the other take hold of the wire; there will be a small spark; but when their lips approach, they will be struck and shock'd. The same if another gentleman and lady, *C* and *D*, standing also on wax, and joining hands with *A* and *B*, salute, or shake hands.—We suspend by fine silk thread a counterfeit spider, made of a small piece of burnt cork, with legs of lin-

nen thread, and a grain or two of lead stuck in him to give him more weight. Upon the table, over which he hangs, we stick a wire upright as high as the phial and wire, two or three inches from the spider; then we animate him by setting the electrified phial at the same distance on the other side of him; he will immediately fly to the wire of the phial, bend his legs in touching it, then spring off and fly to the wire in the table; thence again to the wire of the phial, playing with his legs against both in a very entertaining manner, appearing perfectly alive to persons unacquainted. He will continue this motion an hour or more in dry weather.—We electrify, upon wax in the dark, a book that has a double line of gold round upon the covers, and then apply a knuckle to the gilding; the fire appears every where upon the gold like a flash of lightning: not upon the leather, nor, if you touch the leather instead of the gold. We rub our tubes with buckskin, and observe always to keep the same side to the tube, and never to fully the tube by handling; thus they work readily and easily, without the least fatigue; especially if kept in tight pasteboard cases, lined with flannel, and fitting close to the tube.*—This I mention because the *European* papers, on Electricity, frequently speak of rubbing the tube, as a fatiguing exercise. Our spheres are fixed on iron axes, which pass through them. At one end of the

* Our tubes are made here of green glass, 27 or 30 inches long, as big as can be grasped. Electricity is so much in vogue, that above one hundred of them have been sold within these four months past.

axis there is a small handle, with which we turn the sphere like a common grindstone. This we find very commodious, as the machine takes up but little room, is portable, and may be enclosed in a tight box, when not in use. 'Tis true, the sphere does not turn so swift, as when the great wheel is used : but swiftness we think of little importance, since a few turns will charge the phial, &c. sufficiently.

Yours, &c.

B. FRANKLIN.



LET-

LETTER III.

FROM

Mr BENJ. FRANKLIN, of *Philadelphia*,

TO

Mr PETER COLLINSON, F. R. S. *London*.

Farther EXPERIMENTS and OBSERVATIONS in
ELECTRICITY.

S I R,

1748.

§ 1. **T**Here will be the same explosion and shock, if the electrified phial is held in one hand by the hook, and the coating touch'd with the other, as when held by the coating, and touch'd at the hook.

2. To take the charg'd phial safely by the hook, and not at the same time diminish its force, it must first be set down on an electric *per se*.

3. The phial will be electrified as strongly, if held by the hook, and the coating apply'd to the globe or tube; as when held by the coating, and the hook apply'd.

D 2

4. But

4. But the *direction* of the electrical fire being different in the charging, will also be different in the explosion. The bottle charged thro' the hook, will be discharged thro' the hook; the bottle charged thro' the coating, will be discharged thro' the coating, and not other ways: for the fire must come out the same way it went in.

5. To prove this; take two bottles that were equally charged thro' the hooks, one in each hand; bring their hooks near each other, and no spark or shock will follow; because each hook is disposed to give fire, and neither to receive it. Set one of the bottles down on glass, take it up by the hook, and apply its coating to the hook of the other; then there will be an explosion and shock, and both bottles will be discharged.

6. Vary the experiment, by charging two phials equally, one thro' the hook, the other thro' the coating: hold that by the coating which was charged thro' the hook; and that by the hook which was charg'd thro' the coating: apply the hook of the first to the coating of the other, and there will be no shock or spark. Set that down on glass which you held by the hook, take it up by the coating, and bring the two hooks together: a spark and shock will follow, and both phials be discharged.

In this experiment the bottles are totally discharged, or the equilibrium within them restored. The *abounding* of fire in one of the hooks (or rather in the internal surface of one bottle) being exactly equal to the *wanting* of the other: and therefore, as each bottle has in itself the *abounding* as well

well as the *wanting*, the wanting and abounding must be equal in each bottle. See §. 8, 9, 10, 11. But if a man holds in his hands two bottles, one fully electrify'd, the other not all, and brings their hooks together, he has but half a shock, and the bottles will both remain half electrified, the one being half discharged, and the other half charged.

7. Place two phials equally charged on a table at five or six inches distance. Let a cork-ball, suspended by a silk thread, hang between them. If the phials were both charged through their hooks, the cork, when it has been attracted and repell'd by the one, will not be attracted, but equally repelled by the other. But if the phials were charged, the one through the hook, and the other * through the coating, the ball, when it is repelled from one hook, will be as strongly attracted by the other, and play vigorously between them, 'till both phials are nearly discharged.

8. When we use the terms of *charging* and *discharging* the phial, 'tis in compliance with custom, and for want of others more suitable. Since we are of opinion, that there is really no more electrical fire in the phial after what is called its *charging*, than before, nor less after its *discharging*; excepting only the small spark that might be given to, and taken from, the non-electric matter, if separated from

* To charge a bottle commodiously through the coating, place it on a glass stand; form a communication from the prime conductor to the coating, and another from the hook to the wall or floor. When it is charged, remove the latter communication before you take hold of the bottle, otherwise great part of the fire will escape by it.

the bottle, which spark may not be equal to a five hundredth part of what is called the explosion.

For if, on the explosion, the electrical fire came out of the bottle by one part, and did not enter in again by another; then, if a man standing on wax, and holding the bottle in one hand, takes the spark by touching the wire hook with the other, the bottle being thereby *discharged*, the man would be *charged*; or whatever fire was lost by one, would be found in the other, since there is no way for its escape: But the contrary is true.

9. Besides the phial will not suffer what is called a *charging*, unless as much fire can go out of it one way, as is thrown in by another. A phial cannot be charged standing on wax or glass, or hanging on the prime conductor, unless a communication be form'd between its coating and the floor.

10. But suspend two or more phials on the prime conductor, one hanging to the tail of the other; and a wire from the last to the floor, an equal number of turns of the wheel shall charge them all equally, and every one as much as one alone would have been. What is driven out at the tail of the first, serving to charge the second; what is driven out of the second charging the third; and so on. By this means a great number of bottles might be charged with the same labour, and equally high, with one alone, were it not that every bottle receives new fire, and loses its old with some reluctance, or rather gives some small resistance to the charging, which in a number of bottles becomes

comes more equal to the charging power, and so repels the fire back again on the globe, sooner than a single bottle would do.

11. When a bottle is charged in the common way, its *inside* and *outside* surfaces stand ready, the one to give fire by the hook, the other to receive it by the coating; the one is full, and ready to throw out, the other empty and extremely hungry; yet as the first will not *give out*, unless the other can at the same instant *receive in*; so neither will the latter receive in, unless the first can at the same instant give out. When both can be done at once, 'tis done with inconceivable quickness and violence.

12. So a strait spring (tho' the comparison does not agree in every particular) when forcibly bent, must, to restore itself, contract that side which in the bending was extended, and extend that which was contracted; if either of these two operations be hindered, the other cannot be done. But the spring is not said to be *charg'd* with elasticity when bent, and *discharg'd* when unbent; its quantity of elasticity is always the same.

13. Glass, in like manner, has, within its substance, always the same quantity of electrical fire, and that a very great quantity in proportion to the mass of glass, as shall be shewn hereafter.

14. This quantity, proportioned to the glass, it strongly and obstinately retains, and will have neither more nor less, though it will suffer a change to be made in its parts and situation; *i. e.* we may take away part of it from one
of

of the sides, provided we throw an equal quantity into the other.

15. Yet when the situation of the electrical fire is thus altered in the glass; when some has been taken from one side, and some added to the other, it will not be at rest or in its natural state, till 'tis restored to its original equality.— And this restitution cannot be made through the substance of the glass, but must be done by a non-electric communication formed without, from surface to surface.

16. Thus, the whole force of the bottle, and power of giving a shock, is in the GLASS ITSELF; the non-electrics in contact with the two surfaces, serving only to *give* and *receive* to and from the several parts of the glass; that is, to give on one side, and take away from the other.

17. This was discovered here in the following manner. Purposing to analyse the electrified bottle, in order to find wherein its strength lay, we placed it on glass, and drew out the cork and wire which for that purpose had been loosely put in. Then taking the bottle in one hand, and bringing a finger of the other near its mouth, a strong spark came from the water, and the shock was as violent as if the wire had remained in it, which shewed that the force did not lie in the wire. Then to find if it resided in the water, being crouded into and condensed in it, as confin'd by the glass, which had been our former opinion, we electrify'd the bottle again, and placing it on glass, drew out the wire and cork as before; then taking up the bottle, we decanted all its water into an empty bottle, which likewise stood on glass;

glafs; and taking up that other bottle, we expected if the force refided in the water, to find a fhock from it; but there was none. We judged then, that it muft either be loft in decanting, or remain in the firft bottle. The latter we found to be true: for that bottle on trial gave the fhock, though filled up as it flood with frefh unelectrified water from a tea-pot.—To find then, whether glafs had this property merely as glafs, or whether the form contributed any thing to it; we took a pane of fafh-glafs, and laying it on the hand, placed a plate of lead on its upper furface; then electrify'd that plate, and bringing a finger to it, there was a fpark and fhock. We then took two plates of lead of equal dimenfions, but lefs than the glafs by two inches every way, and electrified the glafs between them, by electrifying the uppermoft lead; then feparated the glafs from the lead, in doing which, what little fire might be in the lead was taken out, and the glafs being touched in the electrified parts with a finger, afforded only very fmall pricking fparks, but a great number of them might be taken from different places. Then dexteroufly placing it again between the leaden plates, and compleating a circle between the two furfaces, a violent fhock enfued.—Which demonftrated the power to refide in glafs as glafs, and that the non-electrics in contact ferved only, like the armature of a loadftone, to unite the force of the feveral parts, and bring them at once to any point defired: it being a property of a non-electric, that

E

the

the whole body instantly receives or gives what electrical fire is given to or taken from any one of its parts.

18. Upon this, we made what we call'd an *electrical-battery*, consisting of eleven panes of large sash-glass, arm'd with thin leaden plates pasted on each side, placed vertically, and supported at two inches distance on silk cords, with thick hooks of leaden wire, one from each side, standing upright, distant from each other, and convenient communications of wire and chain, from the giving side of one pane, to the receiving side of the other; that so the whole might be charged together, and with the same labour as one single pane; and another contrivance to bring the giving sides, after charging, in contract with one long wire, and the receivers with another, which two long wires would give the force of all the plates of glass at once through the body of any animal forming the circle with them. The plates may also be discharged seperately, or any number together that is required. But this machine is not much used, as not perfectly answering our intention with regard to the ease of charging, for the reason given § 10. We made also of large glass panes, magical pictures, and self-moving animated wheels, presently to be described.

19. I perceive by the ingenious Mr *Watson's* last book, lately received, that Dr *Bevis* had used, before we had, panes of glass to give a shock; though, till that book came to hand, I thought to have communicated it to you as a novelty. The excuse for mentioning it here, is, that we
tried

tried the experiment differently, drew different consequences from it, (for Mr *Watson* still seems to think the fire *accumulated on the non-electric* that is in contact with the glass, page 72) and, as far as we hitherto know, have carried it farther.

20. The magical picture is made thus. Having a large metzotinto with a frame and glass, suppose of the KING, (God preserve him) take out the print, and cut a pannel out of it, near two inches distant from the frame all round. If the cut is through the picture 'tis not the worse. With thin paste or gum-water, fix the border that is cut off on the inside of the glass, pressing it smooth and close; then fill up the vacancy by gilding the glass well with leaf gold or brass. Gild likewise the inner edge of the back of the frame all round except the top part, and form a communication between that gilding and the gilding behind the glass: then put in the board, and that side is finished. Turn up the glass, and gild the fore side exactly over the back gilding, and when it is dry, cover it by pasting on the pannel of the picture that hath been cut out, observing to bring the corresponding parts of the border and picture together, by which the picture will appear of a piece as at first, only part is behind the glass, and part before.---Hold the picture horizontally by the top, and place a little moveable gilt crown on the king's-head. If now the picture be moderately electrified, and another person take hold of the frame with one hand, so that his fingers touch its inside gilding, and with the other hand endeavour to take

off the crown, he will receive a terrible blow, and fail in the attempt. If the picture were highly charged, the consequence might perhaps be as fatal as that of high-treason; for when the spark is taken through a quire of paper laid on the picture, by means of a wire communication, it makes a fair hole through every sheet, that is, through 48 leaves, (though a quire of paper is thought good armour against the push of a sword or even against a pistol bullet) and the crack is exceeding loud. The operator, who holds the picture by the upper-end, where the inside of the frame is not gilt, to prevent its falling, feels nothing of the shock, and may touch the face of the picture without danger, which he pretends is a test of his loyalty.—If a ring of persons take the shock among them, the experiment is called, *The Conspirators*.

21. On the principle, in § 7, that hooks of bottles, differently charged, will attract and repel differently, is made an electrical wheel, that turns with considerable strength. A small upright shaft of wood passes at right angles through a thin round board, of about twelve inches diameter, and turns on a sharp point of iron fixed in the lower end, while a strong wire in the upper-end passing thro' a small hole in a thin brass plate, keeps the shaft truly vertical. About thirty *radii* of equal length, made of sash glass cut in narrow strips, issue horizontally from the circumference of the board, the ends most distant from the center being about four inches apart. On the end of every one, a brass thimble is fixed. If now the wire of a bottle electrified in the
common

common way, be brought near the circumference of this wheel, it will attract the nearest thimble, and so put the wheel in motion; that thimble, in passing by, receives a spark, and thereby being electrified is repelled and so driven forwards; while a second being attracted, approaches the wire, receives a spark, and is driven after the first, and so on till the wheel has gone once round, when the thimbles before electrified approaching the wire, instead of being attracted as they were at first, are repelled, and the motion presently ceases.—But if another bottle which had been charged through the coating be placed near the same wheel, its wire will attract the thimble repelled by the first, and thereby double the force that carries the wheel round; and not only taking out the fire that had been communicated to the thimbles by the first bottle, but even robbing them of their natural quantity, instead of being repelled when they come again towards the first bottle, they are more strongly attracted, so that the wheel mends its pace, till it goes with great rapidity twelve or fifteen rounds in a minute, and with such strength, as that the weight of one hundred *Spanish* dollars with which we once loaded it, did not seem in the least to retard its motion.—This is called an electrical jack; and if a large fowl were spitted on the upright shaft, it would be carried round before a fire with a motion fit for roasting.

22. But this wheel, like those driven by wind, water, or weights, moves by a foreign force, to wit, that of the bottles. The self-moving wheel, though constructed on the
same

same principles, appears more surprising. 'Tis made of a thin round plate of window-glass, seventeen inches diameter, well gilt on both sides, all but two inches next the edge. Two small hemispheres of wood are then fixed with cement to the middle of the upper and under sides, centrally opposite, and in each of them a thick strong wire eight or ten inches long, which together make the axis of the wheel. It turns horizontally on a point at the lower end of its axis, which rests on a bit of brass cemented within a glass salt-celler. The upper end of its axis passes thro' a hole in a thin brass plate cemented to a long strong piece of glass, which keeps it six or eight inches distant from any non-electric, and has a small ball of wax or metal on its top to keep in the fire. In a circle on the table which supports the wheel, are fixed twelve small pillars of glass, at about four inches distance, with a thimble on the top of each. On the edge of the wheel is a small leaden bullet communicating by a wire with the gilding of the *upper* surface of the wheel; and about six inches from it is another bullet communicating in like manner with the *under* surface. When the wheel is to be charged by the upper surface, a communication must be made from the under surface to the table. When it is well charg'd it begins to move; the bullet nearest to a pillar moves towards the thimble on that pillar, and passing by electrifies it and then pushes itself from it; the succeeding bullet, which communicates with the other surface of the glass, more strongly attracts that thimble on account of its being before

fore electrified by the other bullet; and thus the wheel increases its motion till it comes to such a height as that the resistance of the air regulates it. It will go half an hour, and make one minute with another twenty turns in a minute, which is six hundred turns in the whole; the bullet of the upper surface giving in each turn twelve sparks, to the thimbles, which makes seven thousand two hundred sparks; and the bullet of the under surface receiving as many from the thimbles; those bullets moving in the time near two thousand five hundred feet.—The thimbles are well fixed, and in so exact a circle, that the bullets may pass within a very small distance of each of them.---If instead of two bullets you put eight, four communicating with the upper surface, and four with the under surface, placed alternately; which eight, at about six inches distance, completes the circumference, the force and swiftness will be greatly increased, the wheel making fifty turns in a minute; but then it will not continue moving so long.—These wheels may be applied, perhaps, to the ringing of chimes, and moving of light-made Orreries.

23. A small wire bent circularly with a loop at each end; let one end rest again the under surface of the wheel, and bring the other end nearer the upper surface, it will give a terrible crack, and the force will be discharged. st

24. Every spark in that manner drawn from the surface of the wheel, makes a round hole in the gilding, tearing off a part of it in coming out; which shews that the fire
is

is not accumulated on the gilding, but is in the glass itself.

25. The gilding being varnish'd over with turpentine varnish, the varnish tho' dry and hard, is burnt by the spark drawn thro' it, and gives a strong smell and visible smoke. And when the spark is drawn through paper, all round the hole made by it, the paper will be blacked by the smoke, which sometimes penetrates several of the leaves. Part of the gilding torn off, is also found forcibly driven into the hole made in the paper by the stroke.

26. 'Tis amazing to observe in how small a portion of glass a great electrical force may lie. A thin glass bubble, about an inch diameter, weighing only six grains, being half-filled with water, partly gilt on the outside, and furnish'd with a wire hook, gives, when electrified, as great a shock as a man can well bear. As the glass is thickest near the orifice, I suppose the lower half, which being gilt was electrified, and gave the shock, did not exceed two grains; for it appeared, when broke, much thinner than the upper half.— If one of these thin bottles be electrified by the coating, and the spark taken out thro' the gilding, it will break the glass inwards at the same time that it breaks the gilding outwards.

27. And allowing (for the reasons before given, § 8, 9, 10,) that there is no more electrical fire in a bottle after charging, than before, how great must be the quantity in this small portion of glass! It seems as if it were of its very substance and essence. Perhaps if that due quantity of electrical

electrical fire so obstinately retained by glass, could be separated from it, it would no longer be glass; it might lose its transparency, or its brittleness, or its elasticity.—Experiments may possibly be invented hereafter, to discover this.

27. We were surprised at the account given in Mr *Watson's* book, of a shock communicated through a great space of dry ground, and suspect there must be some metaline quality in the gravel of that ground; having found that simple dry earth, rammed in a glass tube, open at both ends, and a wire hook inserted in the earth at each end, the earth and wires making part of a circle, would not conduct the least perceptible shock, and indeed when one wire was electrify'd, the other hardly showed any signs of its being in connection with it.—Even a thoroughly wet pack-thread sometimes fails of conducting a shock, tho' it otherwise conducts electricity very well. A dry cake of ice, or an icicle held between two in a circle, likewise prevents the shock; which one would not expect, as water conducts it so perfectly well.---Gilding on a new book, tho' at first it conducts the shock extremely well, yet fails after ten or a dozen experiments, though it appears otherwise in all respects the same, which we cannot account for.

28. There is one experiment more which surprizes us, and is not hitherto satisfactorily accounted for; it is this. Place an iron shot on a glass stand, and let a ball of damp cork, suspended by a silk thread, hang in contact with the

F

shot

shot. Take a bottle in each hand, one that is electrify'd through the hook, the other through the coating: Apply the giving wire to the shot, which will electrify it *positively*, and the cork shall be repelled: Then apply the requiring wire, which will take out the spark given by the other; when the cork will return to the shot: Apply the same again, and take out another spark, so will the shot be electrify'd *negatively*; and the cork in that case shall be repelled equally as before. Then apply the giving wire to the shot, and give the spark it wanted, so will the cork return: Give it another, which will be an addition to its natural quantity, so will the cork be repelled again: And so may the experiment be repeated as long as there is any charge in the bottles. Which shews that bodies having less than the common quantity of Electricity, repel each other, as well as those that have more.

Chagrined a little that we have hitherto been able to produce nothing in this way of use to mankind; and the hot weather coming on, when electrical experiments are not so agreeable, 'tis propos'd to put an end to them for this season, somewhat humorously, in a party of pleasure, on the banks of *Skuylikil**. Spirits, at the same time, are to be fired by a spark sent from side to side through the river, without any other conductor than the water; an experiment which we some time since performed, to the

* The river that washes one side of *Philadelphia*, as the *Delaware* does the other; both are ornamented with the summer habitations, of the citizens, and the agreeable mansions of the principle people of this colony.

amazement of many: A turkey is to be killed for our dinner by the *electrical shock*, and roasted by the *electrical jack*, before a fire kindled by the *electrified bottle*; when the healths of all the famous electricians in *England, Holland, France, and Germany*, are to be drank in * *electrified bumpers*, under the discharge of guns from the *electrical battery*.

* An electrified bumper, is a small thin glass tumbler, near filled with wine, and electrified as the bottle. This when brought to the lips gives a shock, if the party be close shaved, and does not breathe on the liquor.

April 29,
1749.



LETTER IV.

CONTAINING

OBSERVATIONS *and* SUPPOSITIONS,
towards forming a new HYPOTHESIS, *for explaining the several* PHÆNOMENA *of* THUNDER GUSTS*.

S I R,

§. I. **N**ON-ELECTRIC bodies, that have electric fire thrown into them, will retain it till other non-electrics, that have less, approach and then 'tis communicated by a snap, and becomes equally divided.

2. Electrical fire loves water, is strongly attracted by it, and they can subsist together.

3. Air is an electric *per se*, and when dry will not conduct the electrical fire; it will neither receive it, nor give

* Thunder-gusts are sudden storms of thunder and lightning, which are frequently of short duration, but sometimes produce mischievous effects.

it

it to other bodies ; otherwise no body surrounded by air could be electrified positively and negatively : for should it be attempted positively, the air would immediately take away the overplus ; or negatively, the air would supply what was wanting.

4. Water being electrified, the vapours arising from it will be equally electrified ; and floating in the air, in the form of clouds, or otherwise, will retain that quantity of electrical fire, till they meet with other clouds or bodies not so much electrified, and then will communicate as beforementioned.

5. Every particle of matter electrified is repelled by every other particle equally electrified. Thus the stream of a fountain, naturally dense and continual, when electrified, will separate and spread in the form of a brush, every drop endeavouring to recede from every other drop. But on taking out the electrical fire, they close again.

6. Water being strongly electrified (as well as when heated by common fire) rises in vapours more copiously ; the attraction of cohesion among its particles being greatly weakened, by the opposite power of repulsion introduced with the electrical fire ; and when any particle is by any means disengaged, 'tis immediately repelled, and so flies into the air.

7. Particles happening to be situated as *A* and *B*, are more easily disengaged than *C* and *D*, as each is held by contact with three only, whereas *C* and *D* are each in contact with nine. When the surface of water has the
least

least motion, particles are continually pushed into the situation represented by *A* and *B*, FIG. 6.

8. Friction between a non-electric and an electric *per se* will produce electrical fire; not by *creating*, but *collecting* it: for it is equally diffused in our walls, floors, earth, and the whole mass of common matter. Thus the whirling glass globe, during its friction against the cushion, draws fire from the cushion, the cushion is supplied from the frame of the machine, that from the floor on which it stands. Cut off the communication by thick glass or wax placed under the cushion, and no fire can be *produced*, because it cannot be *collected*.

9. The Ocean is a compound of water, a non-electric, and salt an electric *per se*.

10. When there is a friction among the parts near its surface, the electrical fire is collected from the parts below. It is then plainly visible in the night; it appears at the stern and in the wake of every sailing vessel; every dash of an oar shows it, and every surff and spray: in storms the whole sea seems on fire.---The detach'd particles of water then repelled from the electrified surface, continually carry off the fire as it is collected; they rise, and form clouds, and those clouds are highly electrified, and retain the fire till they have an opportunity of communicating it.

11. The particles of water rising in vapours, attach themselves to particles of air.

12. The particles of air are said to be hard, round, separate and distant from each other; every particle strongly repelling

repelling every other particle, whereby they recede from each other, as far as common gravity will permit.

13. The space between any three particles equally repelling each other, will be an equilateral triangle.

14. In air compressed, these triangles are smaller; in rarified Air they are larger.

15. Common fire joined with air, increases the repulsion, enlarges the triangles, and thereby makes the air specifically lighter. Such Air among denser air, will rise.

16. Common fire, as well as electrical fire gives repulsion to the particles of water, and destroys their attraction of cohesion; hence common fire, as well as electrical fire, assists in raising vapours.

17. Particles of water, having no fire in them, mutually attract each other. Three particles of water then being attached to the three particles of a triangle of air, would by their mutual attraction operating against the air's repulsion, shorten the sides and lessen the triangle, whereby that portion of air being made denser, would sink to the earth with its water, and not rise to contribute to the formation of a cloud.

18. But if every particle of water attaching itself to air, brings with it a particle of common fire, the repulsion of the air being assisted and strengthened by the fire, more than obstructed by the mutual attraction of the particles of water, the triangle dilates, and that portion of air becoming rarer and specifically lighter rises.

19. If the particles of water bring electrical fire when
they

they attach themselves to air, the repulsion between the particles of water electrified, joins with the natural repulsion of the air, to force its particles to a greater distance, whereby the triangles are dilated, and the air rises, carrying up with it the water.

20. If the particles of water bring with them portions of *both sorts* of fire, the repulsion of the particles of air is still more strengthened and increased, and the triangles farther enlarged.

21. One particle of air may be surrounded by twelve particles of water of equal size with itself, all in contact with it; and by more added to those.

22. Particles of air thus loaded would be drawn nearer together by the mutual attraction of the particles of water, did not the fire, common or electrical, assist their repulsion.

23. If air thus loaded be compressed by adverse winds, or by being driven against mountains, &c. or condensed by taking away the fire that assisted it in expanding; the triangles contract, the air with its water will descend as a dew; or, if the water surrounding one particle of air comes in contact with the water surrounding another, they coalesce and form a drop, and we have rain.

24. The sun supplies (or seems to supply) common fire to all vapours, whether raised from earth or sea.

25. Those vapours which have both common and electrical fire in them; are better supported, than those which have only common fire in them. For when vapours rise
into

into the coldest region above the earth, the cold will not diminish the electrical fire, if it doth the common.

26. Hence clouds formed by vapours raised from fresh waters within land, from growing vegetables, moist earth, &c. more speedily and easily depofite their water, having but little electrical fire to repel and keep the particles separate. So that the greatest part of the water raised from the land is let fall on the land again; and winds blowing from the land to the sea are dry; there being little use for rain on the sea, and to rob the land of its moisture, in order to rain on the sea, would not appear reasonable.

27. But clouds formed by vapours raised from the sea, having both fires, and particularly a great quantity of the electrical, support their water strongly, raise it high, and being moved by winds may bring it over the middle of the broadest continent from the middle of the widest ocean.

28. How these ocean clouds, so strongly supporting their water, are made to depofite it on the land where 'tis wanted, is next to be considered.

29. If they are driven by winds against mountains, those mountains being less electrified attract them, and on contact take away their electrical fire (and being cold, the common fire also;) hence the particles close towards the mountains and towards each other. If the air was not much loaded, it only falls in dews on the mountain tops and sides, forms springs, and descends to the vales in rivulets, which united make larger streams and rivers. If much loaded, the electrical fire is at once taken from the

G

whole

whole cloud ; and, in leaving it, flashes brightly and cracks loudly ; the particles instantly coalescing for want of that fire, and falling in a heavy shower.

30. When a ridge of mountains thus dams the clouds, and draws the electrical fire from the cloud first approaching it ; that which next follows, when it comes near the first cloud, now deprived of its fire, flashes into it, and begins to deposite its own water ; the first cloud again flashing into the mountains ; the third approaching cloud, and all the succeeding ones, acting in the same manner as far back as they extend, which may be over many hundred miles of country.

31. Hence the continual storms of rain, thunder, and lightning on the east-side of the *Andes*, which running north and south, and being vastly high, intercept all the clouds brought against them from the *Atlantic* ocean by the trade winds, and oblige them to deposite their waters, by which the vast rivers *Amazons*, *La Plata*, and *Oroonoko* are formed, which return the water into the same sea, after having fertilized a country of very great extent.

32. If a country be plain, having no mountains to intercept the electrified clouds, yet it is not without means to make them deposite their water. For if an electrified cloud coming from the sea, meets in the air a cloud raised from the land, and therefore not electrified ; the first will flash its fire into the latter, and thereby both clouds shall be made suddenly to deposite water.

33. The electrified particles of the first cloud close when they loose their fire ; the particles of the other cloud close

close in receiving it: in both, they have thereby an opportunity of coalescing into drops.---The concussion or jerk given to the air, contributes also to shake down the water, not only from those two clouds but from others near them. Hence the sudden fall of rain immediately after flashes off lightning.

34. To shew this by an easy experiment: Take two round pieces of pasteboard two inches diameter; from the center and circumference of each of them suspend by fine silk threads eighteen inches long, seven small balls of wood, or seven peas equal in bigness; so will the balls appending to each pasteboard, form equal equilateral triangles, one ball being in the center, and six at equal distances from that, and from each other; and thus they represent particles of air. Dip both sets in water, and some cohering to each ball they will represent air loaded. Dexterously electrifyd one set, and its balls will repel each other to a greater distance, enlarging the triangles. Could the water supported by the seven balls come into contact, it would form a drop or drops so heavy as to break the cohesion it had with the balls, and so fall.---Let the two sets then represent two clouds, the one a sea cloud electrified, the other a land cloud. Bring them within the sphere of attraction, and they will draw towards each other, and you will see the separated balls close thus; the first electrified ball that comes near an unelectrified ball by attraction joins it, and gives it fire; instantly they separate, and each flies to another ball of its own party, one to

give, the other to receive fire; and so it proceeds through both sets, but so quick as to be in a manner instantaneous. In the collision they shake off and drop their water, which represents rain.

35. Thus when sea and land clouds would pass at too great a distance for the flash, they are attracted towards each other till within that distance; for the sphere of electrical attraction is far beyond the distance of flashing.

36. When a great number of clouds from the sea meet a number of clouds raised from the land, the electrical flashes appear to strike in different parts; and as the clouds are jostled and mixed by the winds, or brought near by the electrical attraction, they continue to give and receive flash after flash, till the electrical fire is equally diffused.

37. When the gun-barrel (in electrical experiments) has but little electrical fire in it, you must approach it very near with your knuckle, before you can draw a spark. Give it more fire, and it will give a spark at a greater distance. Two gun-barrels united, and as highly electrified, will give a spark at a still greater distance. But if two gun-barrels electrified will strike at two inches distance, and make a loud snap, to what a great distance may 10,000 acres of electrified cloud strike and give its fire, and how loud must be that crack?

38. It is a common thing to see clouds at different heights passing different ways, which shews different currents of air, one under the other. As the air between the
tropics

tropics is rarified by the sun, it raises, the denser northern and southern air pressing into its place. The air so rarified and forced up, passes northward and southward, and must descend in the polar regions, if it has no opportunity before, that the circulation may be carried on.

39. As currents of air, with the clouds therein, pass different ways, 'tis easy to conceive how the clouds, passing over each other, may attract each other, and so come near enough for the electrical stroke. And also how electrical clouds may be carried within land very far from the sea, before they have an opportunity to strike.

40. When the air, with its vapours raised from the ocean between the tropics, comes to descend in the polar regions, and to be in contact with the vapours arising there, the electrical fire they brought begins to be communicated, and is seen in clear nights, being first visible where 'tis first in motion, that is, where the contact begins, or in the most northern part; from thence the streams of light seem to shoot southerly, even up to the zenith of northern countries. But tho' the light seems to shoot from the north southerly, the progress of the fire is really from the south northerly, its motion beginning in the north being the reason that 'tis there first seen. r

For the electrical fire is never visible but when in motion, and leaping from body to body, or from particle to particle thro' the air. When it passes thro' dense bodies 'tis unseen. When a wire makes part of the circle, in the explosion of the electrical phial, the fire, though in great quantity

quantity, passes in the wire invisibly : but in passing along a chain, it becomes visible as it leaps from link to link. In passing along leaf-gilding 'tis visible : for the leaf-gold is full of pores ; hold a leaf to the light and it appears like a net ; and the fire is seen in its leaping over the vacancies.— And as when a long canal filled with still water is opened at one end, in order to be discharged, the motion of the water begins first near the opened end, and proceeds towards the close end, tho' the water itself moves from the close towards the opened end : so the electrical fire discharged into the polar regions, perhaps from a thousand leagues length of vaporiz'd air, appears first where 'tis first in motion, *i. e.* in the most northern part, and the appearance proceeds southward, tho' the fire really moves northward. This is supposed to account for the *Aurora Borealis*.

41. When there is great heat on the land, in a particular region (the sun having shone on it perhaps several days, while the surrounding countries have been screen'd by clouds) the lower air is rarified and rises, the cooler denser air above descends ; the clouds in that air meet from all sides, and join over the heated place ; and if some are electrified, others not, lightning and thunder succeed, and showers fall. Hence thunder-gusts after heats, and cool air after gusts ; the water and the clouds that bring it, coming from a higher and therefore a cooler region.

42. An electrical spark, drawn from an irregular body at some distance is scarce ever strait, but shows crooked

ed and waving in the air. So do the flashes of lightning; the clouds being very irregular bodies.

43. As electrified clouds pass over a country, high hills and high trees, lofty towers, spires, masts of ships, chimneys, &c. as so many prominencies and points, draw the electrical fire, and the whole cloud discharges there.

44. Dangerous, therefore, is it to take shelter under a tree during a thunder-gust. It has been fatal to many, both men and beasts.

45. It is safer to be in the open field for another reason. When the clothes are wet, if a flash in its way to the ground should strike your head, it will run in the water over the surface of your body; whereas, if your clothes were dry, it would go through the body.

Hence a wet rat cannot be killed by the exploding electrical bottle, when a dry rat may.

46. Common fire is in all bodies, more or less, as well as electrical fire. Perhaps they may be different modifications of the same element; or they may be different elements. The latter is by some suspected.

47. If they are different things, yet they may and do subsist together in the same body.

48. When electrical fire strikes through a body, it acts upon the common fire contained in it, and puts that fire in motion; and if there be a sufficient quantity of each kind of fire, the body will be inflamed.

49. When the quantity of common fire in the body is small, the quantity of the electrical fire (or the electrical stroke)

stroke) should be greater: if the quantity of common fire be great, less electrical fire suffices to produce the effect.

50. Thus spirits must be heated before we can fire them by the electrical spark. If they are much heated a small spark will do; if not, the spark must be greater.

51. 'Till lately we could only fire warm vapours; but now we can burn hard dry rosin. And when we can procure greater electrical sparks, we may be able to fire not only unwarm'd spirits, as lightning does, but even wood, by giving sufficient agitation to the common fire contained in it, as friction we know will do.

52. Sulphureous and inflammable vapours arising from the earth, are easily kindled by lightning. Besides what arise from the earth, such vapours are sent out by stacks of moist hay, corn, or other vegetables, which heat and reek. Wood rotting in old trees or buildings does the same. Such are therefore easily and often fired.

53. Metals are often melted by lightning, tho' perhaps not from heat in the lightning, nor altogether from agitated fire in the metals.—For as whatever body can insinuate itself between the particles of metal, and overcome the attraction by which they cohere (as fundry menstrua can) will make the solid become a fluid, as well as fire, yet without heating it: so the electrical fire, or lightning, creating a violent repulsion between the particles of the metal it passes thro', the metal is fused.

54. If you would, by a violent fire, melt off the end of a nail, which is half driven into a door, the heat given the whole

whole nail before a part would melt, must burn the board it sticks in. And the melted part would burn the floor it dropp'd on. But if a sword can be melted in the scabbard, and money in a man's pocket, by lightning, without burning either, it must be a cold fusion.

55. Lightning rends some bodies. The electrical spark will strike a hole thro' a quire of strong paper.

56. If the source of lightning, assigned in this paper, be the true one, there should be little thunder heard at sea far from land. And accordingly some old sea-captains, of whom enquiry has been made, do affirm, that the fact agrees perfectly with the hypothesis; for that, in crossing the great ocean, they seldom meet with thunder till they come into soundings; and that the islands far from the continent have very little of it. And a curious observer, who lived 13 years at *Bermudas*, says, there was less thunder there in that whole time than he has sometimes heard in a month at *Carolina*.

ADDITIONAL PAPERS.

T O

Mr PETER COLLINSON, F. R. S. *London.*

S I R,

PHILADELPHIA, *July 29, 1750*

AS you first put us on electrical experiments, by sending to our library company a tube, with directions how to use it; and as our honourable proprietary enabled us to carry those experiments to a greater height, by this generous present of a compleat electrical apparatus; 'tis fit that both should know from time to time what progress we make. It was in this view I wrote and sent you my former papers on this subject, desiring, that as I had not the honour of a direct correspondence with that bountiful benefactor to our library, they might be communicated to him through your hands. In the same view I write, and send you this additional paper. If it happens to bring you nothing new (which may well be, considering the number of ingenious men in *Europe*, continually engaged in the same researches) at least it will show, that the instruments, put into our hands, are not neglected; and, that if no valuable discoveries are made by us, whatever the cause may be, it is not want of industry and application.

I am, Sir,

Your much obliged.

Humble Servant,

B. FRANKLIN.

OPINIONS and CONJECTURES,
Concerning the Properties and Effects of the electrical Matter, arising from Experiments and Observations, made at Philadelphia, 1749.

§. 1. **T**HE electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom, as not to receive any perceptible resistance.

2. If any one should doubt, whether the electrical matter passes thro' the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken thro' his own body, will probably convince him.

3. Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel, each other. Hence the appearing divergency in a stream of electrified effluvia.

4. But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.*

* See the ingenious essays on electricity in the Transactions, by Mr Ellicot.

5. From these three things, the extreme subtility of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that when a quantity of electrical matter, is applied to a mass of common matter, of any bigness or length within our observation (which has not already got its quantity) it is immediately and equally diffused through the whole.

6. Thus common matter is a kind of sponge to the electrical fluid. And as a sponge would receive no water, if the parts of water were not smaller than the pores of the sponge; and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them, and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the sponge. So is the case between the electrical and common matter.

7. But in common matter there is (generally) as much of the electrical, as it will contain within its substance. If more is added, it lies without upon the surface, and forms, what we call an electrical atmosphere: and then the body is said to be electrified.

8. 'Tis supposed, that all kinds of common matter do not attract and retain the electrical, with equal strength and force; for reasons to be given hereafter. And that those
called

called electrics *per se*, as glass, &c. attract and retain it strongest, and contain the greatest quantity.

9. We know that the electrical fluid is *in* common matter, because we can pump it *out* by the globe or tube. We know that common matter has near as much as it can contain, because, when we add a little more to any portion of it, the additional quantity does not enter, but forms an electrical atmosphere. And we know that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each other, as they constantly do when they have electric atmospheres.

10. The beneficial uses of this electrical fluid in the creation, we are not yet well acquainted with, though doubtless such there are, and those very considerable; but we may see some pernicious consequences, that would attend a much greater proportion of it. For had this globe we live on as much of it in proportion, as we can give to a globe of iron, wood, or the like, the particles of dust and other light matters that get loose from it, would, by virtue of their separate electrical atmospheres, not only repel each other, but be repelled from the earth, and not easily be brought to unite with it again; whence our air would continually be more and more clogged with foreign matter, and grow unfit for respiration. This affords another occasion of adoring that wisdom which has made all things by weight and measure!

11. If a piece of common matter be supposed entirely free from electrical matter, and a single particle of the latter

latter be brought nigh, 'twill be attracted and enter the body, and take place in the center, or where the attraction is every way equal. If more particles enter, they take their places where the balance is equal between the attraction of the common matter and their own mutual repulsion. 'Tis supposed they form triangles, whose sides shorten as their number encreases; 'till the common matter has drawn in so many, that its whole power of compressing those triangles by attraction, is equal to their whole power of expanding themselves by repulsion; and then will such piece of matter receive no more.

12. When part of this natural proportion of electrical fluid, is taken out of a piece of common matter, the triangles formed by the remainder, are supposed to widen by the mutual repulsion of the parts, until they occupy the whole piece.

13. When the quantity of electrical fluid taken from a piece of common matter is restored again, it enters, the expanded triangles being again compressed till there is room for the whole.

14. To explain this: take two apples, or two balls of wood or other matter, each having its own natural quantity of the electrical fluid. Suspend them by silk lines from the ceiling. Apply the wire of a well-charged vial, held in your hand, to one of them (A) Fig. 7. and it will receive from the wire a quantity of the electrical fluid; but will not imbibe it, being already full. The fluid therefore will flow round its surface, and form an electrical atmosphere.

Bring

Bring A into contact with B, and half the electrical fluid is communicated, so that each has now an electrical atmosphere, and therefore they repel each other. Take away these atmospheres by touching the balls, and leave them in their natural state: then, having fixed a stick of sealing wax to the middle of the vial to hold it by, apply the wire to A, at the same time the coating touches B. Thus will a quantity of the electrical fluid be drawn out of B, and thrown on A. So that A will have a redundancy of this fluid, which forms an atmosphere round it, and B an exactly equal deficiency. Now bring these balls again into contact, and the electrical atmosphere will not be divided between A and B, into two smaller atmospheres as before; for B will drink up the whole atmosphere of A, and both will be found again in their natural state.

15. The form of the electrical atmosphere is that of the body it surrounds. This shape may be rendered visible in a still air, by raising a smoke from dry rosin, dropt into a hot tea-spoon under the electrified body, which will be attracted and spread itself equally on all sides, covering and concealing the body. And this form it takes, because it is attracted by all parts of the surface of the body, tho' it cannot enter the substance already replete. Without this attraction it would not remain round the body, but dissipate in the air.

16. The atmosphere of electrical particles surrounding an electrified sphere, is not more disposed to leave it or
more

more easily drawn off from any one part of the sphere than from another, because it is equally attracted by every part. But that is not the case with bodies of any other figure. From a cube it is more easily drawn at the corners than at the plane sides, and so from the angles of a body of any other form, and still most easily from the angle that is most acute. Thus if a body shaped as A, B, C, D, E, in Fig. 8, be electrified, or have an electrical atmosphere communicated to it, and we consider every side as a base on which the particles rest, and by which they are attracted, one may see, by imagining a line from A to F, and another from E to G, that the portion of the atmosphere included in F, A, E, G, has the line A, E, for its basis. So the portion of atmosphere included in H, A, B, I, has the line A, B, for its basis. And likewise the portion included in K, B, C, L, has B, C, to rest on; and so on the other side of the figure. Now if you would draw off this atmosphere with any blunt smooth body, and approach the middle of the side A, B, you must come very near before the force of your attracter exceeds the force or power with which that side holds its atmosphere. But there is a small portion between I, B, K, that has less of the surface to rest on, and to be attracted by, than the neighbouring portions, while at the same time there is a mutual repulsion between its particles and the particles of those portions, therefore here you can get it with more ease or at a greater distance. Between F, A, H, there is a larger portion that has yet a less surface to rest on and to attract it;
here

here therefore you can get it away still more easily. But easiest of all between L, C, M, where the quantity is largest, and the surface to attract and keep it back the least. When you have drawn away one of these angular portions of the fluid, another succeeds in its place, from the nature of fluidity and the mutual repulsion beforementioned; and so the atmosphere continues flowing off at such angle, like a stream, till no more is remaining. The extremities of the portions of atmosphere over these angular parts are likewise at a greater distance from the electrified body, as may be seen by the inspection of the above figure; the point of the atmosphere of the angle C, being much farther from C, than any other part of the atmosphere over the lines C, B, or B, A: And besides the distance arising from the nature of the figure, where the attraction is less, the particles would naturally expand to a greater distance by their mutual repulsion. On these accounts we suppose electrified bodies discharge their atmospheres upon unelectrified bodies more easily and at a greater distance from their angles and points than from their smooth sides.—Those points will also discharge into the air, when the body has too great an electrical atmosphere, without bringing any non-electric near, to receive what is thrown off: For the air, though an electric *per se*, yet has always more or less water and other non-electric matters mixed with it; and these attract and receive what is so discharged.

17. But points have a property, by which they *draw on* as well as *throw off* the electrical fluid, at greater distances

I

than

than blunt bodies can. That is, as the pointed part of an electrified body will discharge the atmosphere of that body, or communicate it farthest to another body, so the point of an unelectrified body, will draw off the electrical atmosphere from an electrified body, farther than a blunter part of the same unelectrified body will do. Thus a pin held by the head, and the point presented to an electrified body, will draw off its atmosphere at a foot distance; where if the head were presented instead of the point, no such effect would follow. To understand this, we may consider, that if a person standing on the floor would draw off the electrical atmosphere from an electrified body, an iron crow and a blunt knitting kneedle held alternately in his hand and presented for that purpose, do not draw with different forces in proportion to their different masses. For the man, and what he holds in his hand, be it large or small, are connected with the common mass of unelectrified matter; and the force with which he draws is the same in both cases, it consisting in the different proportion of electricity in the electrified body and that common mass. But the force with which the electrified body retains its atmosphere by attracting it, is proportioned to the surface over which the particles are placed; *i. e.* four square inches of that surface retain their atmosphere with four times the force that one square inch retains its atmosphere. And as in plucking the hairs from the horse's tail, a degree of strength insufficient to pull away a handful at once, could yet easily strip it hair by hair

hair; so a blunt body presented cannot draw off a number of particles at once, but a pointed one, with no greater force, takes them away easily, particle by particle.

18. These explanations of the power and operation of points, when they first occur'd to me, and while they first floated in my mind, appeared perfectly satisfactory; but now I have wrote them, and consider'd them more closely in black and white, I must own I have some doubts about them: yet as I have at present nothing better to offer in their stead, I do not cross them out: for even a bad solution read, and its faults discover'd, has often given rise to a good one in the mind of an ingenious reader.

19. Nor is it of much importance to us, to know the manner in which nature executes her laws; 'tis enough if we know the laws themselves. 'Tis of real use to know, that china left in the air unsupported will fall and break; but *how* it comes to fall, and *why* it breaks, are matters of speculation. 'Tis a pleasure indeed to know them, but we can preserve our china without it.

20. Thus in the present case, to know this power of points, may possibly be of some use to mankind, though we should never be able to explain it. The following experiments, as well as those in my first paper, show this power. I have a large prime conductor made of several thin sheets of Fuller's pasteboard form'd into a tube, near 10 feet long and a foot diameter. It is cover'd with *Dutch* embross'd paper, almost totally gilt. This large

metallic surface supports a much greater electrical atmosphere than a rod of iron of 50 times the weight would do. It is suspended by silk lines, and when charg'd will strike at near two inches distance, a pretty hard stroke so as to make one's knuckle ach. Let a person standing on the floor present the point of a needle at 12 or more inches distance from it, and while the needle is so presented, the conductor cannot be charged, the point drawing off the fire as fast as it is thrown on by the electrical globe. Let it be charged, and then present the point at the same distance, and it will suddenly be discharged. In the dark you may see a light on the point, when the experiment is made. And if the person holding the point stands upon wax, he will be electrified by receiving the fire at that distance. Attempt to draw off the electricity with a blunt body, as a bolt of iron round at the end and smooth (a silversmith's iron punch, inch-thick, is what I use) and you must bring it within the distance of three inches before you can do it, and then it is done with a stroke and crack. As the pasteboard tube hangs loose on silk lines, when you approach it with the punch iron, it likewise would move towards the punch, being attracted while it is charged; but if at the same instant a point be presented as before, it retires again, for the point discharges it. Take a pair of large brass scales, of two or more feet beam, the cords of the scales being silk. Suspend the beam by a packthread from the cieling, so that the bottom of the scales may be about a foot from the floor:

floor : The scales will move round in a circle by the untwisting of the packthread. Set the iron punch on the end upon the floor, in such a place as that the scales may pass over it in making their circle : Then electrify one scale by applying the wire of a charged phial to it. As they move round, you see that scale draugh nigher to the floor, and dip more when it comes over the punch ; and if that be placed at a proper distance, the scale will snap and discharge its fire into it. But if a needle be stuck on the end of the punch, its point upwards, the scale, instead of drawing nigh to the punch and snapping, discharges its fire silently through the point, and rises higher from the punch. Nay, even if the needle be placed upon the floor near the punch, its point upwards, the end of the punch, tho' so much higher than the needle, will not attract the scale and receive its fire, for the needle will get it and convey it away, before it comes nigh enough for the punch to act. And this is constantly observable in these experiments, that the greater quantity of electricity on the pasteboard tube, the farther it strikes or discharges its fire, and the point likewise will draw it off at a still greater distance.

Now if the fire of electricity and that of lightening be the same, as I have endeavour'd to shew at large in a former paper, this pasteboard tube and these scales may represent electrified clouds. If a tube of only 10 feet long will strike and discharge its fire on the punch at two or three inches distance, an electrified cloud of perhaps

haps 10,000 acres, may strike and discharge on the earth at a proportionably greater distance. The horizontal motion of the scales over the floor, may represent the motion of the clouds over the earth; and the erect iron punch a hill or high building; and then we see how electrified clouds passing over hills or high buildings at too great a height to strike, may be attracted lower till within their striking distance. And lastly, if a needle fix'd on the punch with its point upwright, or even on the floor below the punch, will draw the fire from the scale silently at a much greater than the striking distance, and so prevent its descending towards the punch; or if in its course it would have come nigh enough to strike, yet being first deprived of its fire it cannot, and the punch is thereby secured from the stroke. I say, if these things are so, may not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, &c. from the stroke of lightning, by directing us to fix on the highest part of those edifices, upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?

21. To determine the question, whether the clouds
that

that contain lightning are electrified or not, I would propose an experiment to be try'd where it may be done conveniently. On the top of some high tower or steeple, place a kind of centry-box, (as in FIG. 9.) big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upwright 20 or 30 feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified and afford sparks, the rod drawing fire to him from a cloud. If any danger to the man should be apprehended (though I think there would be none) let him stand on the floor of his box, and now and then bring near to the rod, the loop of a wire that has one end fastened to the leads, he holding it by a wax handle; so the sparks, if the rod is electrified, will strike from the rod to the wire, and not affect him.

22. Before I leave this subject of lightning, I may mention some other similarities between the effects of that, and these of electricity. Lightning has often been known to strike people blind. A pigeon that we struck dead to appearance by the electrical shock, recovering life, droop'd about the yard several days, eat nothing though crumbs were thrown to it, but declined and died. We did not think of its being deprived of sight; but afterwards a pullet struck dead in like manner, being recovered by repeatedly blowing into its lungs, when set down on the floor, ran headlong against the wall, and on examination
appear-

appeared perfectly blind. Hence we concluded that the pigeon also had been absolutely blinded by the shock. The biggest animal we have yet killed or try'd to kill with the electrical stroke, was a well grown pullet.

23. Reading in the ingenious Dr. *Miles's* account of the thunder storm at *Stretham*, the effect of the lightning in stripping off all the paint that had covered a gilt moulding of a pannel of waincot, without hurting the rest of the paint, I had a mind to lay a coat of paint over the filleting of gold on the cover of a book, and try the effect of a strong electrical flash sent through that gold from a charged sheet of glass. But having no paint at hand, I pasted a narrow strip of paper over it; and when dry, sent the flash through the gilding; by which the paper was torn off from end to end, with such force, that it was broke in several places, and in others brought away part of the grain of the Turkey-leather in which it was bound: and convinced me, that had it been painted, the paint would have been stript off in the same manner with that on the wainscoat at *Stretham*.

24. Lightning melts mettals, and I hinted in my paper on that subject, that I suspected it to be a cold fusion; I do not mean a fusion by force of cold, but a fusion without heat. We have also melted gold, silver, and copper, in small quantities, by the electrical flash. The manner is this: Take leaf gold, leaf silver, or leaf gilt copper, commonly called leaf brass or *Dutch gold*: cut off from the leaf long narrow strips the bredth of
a straw

a straw. Place one of these strips between two strips of smooth glass that are about the width of your finger. If one strip of gold, the length of the leaf, be not long enough for the glass, add another to the end of it, so that you may have a little part hanging out loose at each end of the glass. Bind the pieces of glass together from end to end with strong silk thread; then place it so as to be part of an electrical circle, (the ends of gold hanging out being of use to join with the other parts of the circle) and send the flash through it, from a large electrified jar or sheet of glass. Then if your strips of glass remain whole, you will see that the gold is missing in several places, and instead of it a metallic stain on both the glasses; the stains on the upper and under glass exactly similar in the minutest stroke, as may be seen by holding them to the light; the metal appeared to have been not only melted, but even vetrified, or otherwise so driven into the pores of the glass, as to be protected by it from the action of the strongest *Aqua Fortis* and *Aqua Regia*. I send you enclosed two little pieces of glass with these metallic stains upon them, which cannot be removed without taking part of the glass with them. Sometimes the stain spreads a little wider than the breadth of the leaf, and looks brighter at the edge, as by inspecting closely you may observe in these. Sometimes the glass breaks to pieces: once the upper glass broke into a thousand pieces, looking like coarse salt. These pieces I send you, were stain'd with *Dutch* gold. True gold makes a darker stain,

K

somewhat

somewhat reddish; silver, a greenish stain. We once took two pieces of thick looking-glass, as broad as a Gunter's scale, and 6 inches long; and placing leaf gold between them, put them betwixt two smoothly plain'd pieces of wood, and fix'd them tight in a book-binder's small press; yet though they were so closely confined, the force of the electrical shock shivered the glass into many pieces. The gold was melted and stain'd into the glass as usual. The circumstances of the breaking of the glass differ much in making the experiment, and sometimes it does not break at all: but this is constant, that the stains in the upper and under pieces are exact counterparts of each other. And though I have taken up the pieces of glass between my fingers immediately after this melting, I never could perceive the least warmth in them.

25. In one of my former papers, I mention'd, that gilding on a book, though at first it communicated the shock perfectly well, yet fail'd after a few experiments, which we could not account for. We have since found, that one strong shock breaks the continuity of the gold in the filleting, and makes it look rather like dust of gold, abundance of its parts being broken and driven off; and it will seldom conduct above one strong shock. Perhaps this may be the reason; when there is not a perfect continuity in the circle, the fire must leap over the vacancies; there is a certain distance which it is able to leap over according to its strength; if a number of small vacancies, though each be very minute, taken together

gether exceed that distance, it cannot leap over them, and so the shock is prevented.

26. From the before mentioned law of electricity, that points, as they are more or less acute, draw on and throw off the electrical fluid with more or less power, and at greater or less distances, and in larger or smaller quantities in the same time, we may see how to account for the situation of the leaf of gold suspended between two plates, the upper one continually electrified, the under one in a person's hand standing on the floor. When the upper plate is electrified, the leaf is attracted and raised towards it, and would fly to that plate were it not for its own points. The corner that happens to be uppermost when the leaf is rising, being a sharp point, from the extream thinness of the gold, draws and receives at a distance a sufficient quantity of the electrical fluid to give itself an electrical atmosphere, by which its progress to the upper plate is stopt, and it begins to be repelled from that place, and would be driven back to the under plate, but that its lowest corner is likewise a point, and throws off or discharges the overplus of the leaf's atmosphere, as fast as the upper corner draws it on. Were these two points perfectly equal in acuteness, the leaf would take place exactly in the middle space, for its Weight is a trifle, compared to the power acting on it: But it is generally nearest the unelectrified plate, because, when the leaf is offered to the electrified plate at a distance, the sharpest point is commonly first affected and raised towards it; so that point, from its greater a-

cuteness, receiving the fluid faster than its opposite can discharge it at equal distances, it retires from the electrified plate, and draws nearer to the unelectrified plate, till it comes to a distance where the discharge can be exactly equal to the receipt, the latter being lessened, and the former encreased; and there it remains as long as the globe continues to supply fresh electrical matter. This will appear plain, when the difference of acuteness in the corners is made very great. Cut a piece of *Dutch* gold (which is fittest for these experiments on account of its greater strength) into the form of FIG. 10, the upper corner a right angle, the two next obtuse angles, and the lowest a very acute one; and bring this on your plate under the electrified plate, in such a manner as that the right-angled part may be first raised (which is done by covering the acute part with the hollow of your hand) and you will see this leaf take place much nearer to the upper than to the under plate; because without being nearer, it cannot receive so fast at its right-angled point, as it can discharge at its acute one. Turn this leaf with the acute part uppermost, and then it takes place nearest the unelectrified plate; because, otherwise it receives faster at its acute point than it can discharge at its right-angled one. Thus the difference of distance is always proportioned to the difference of acuteness. Take care in cutting your leaf to leave no little ragged particles on the edges, which sometimes form points where you would not have them. You may make this figure

figuer so acute below and blunt above, as to need no undre plate, it discharging fast enough into the air. When it is made narrower, as the figure between the pricked lines, we call it the *Golden Fish*, from its manner of acting. For if you take it by the tail, and hold it at a foot or greater horizontal distance from the prime conductor, it will, when let go, fly to it with a brisk but wavering motion, like that of an eel through the water; it will then take place under the prime conductor, at perhaps a quarter or half an inch distance, and keep a continual shaking of its tail like a fish so that it seems animated. Turn its tail towards the prime conductor, and then it flies to your figure, and seems to nibble it. And if you hold a plate under it at six or eight inches distance, and cease turning the Globe, when the electrical atmosphere of the conductor grows small, it will descend to the plate and swim back again several times with the same fish-like motion, greatly to the entertainment of spectators. By a little practice in blunting or sharpening the heads or tails of these figures, you may make them take place as desired, nearer, or farther from the electrified plate.

27. It is said in section 8, of this paper, that all kinds of common matter are supposed not to attract the electrical fluid with equal strength; and that those called *electrics per se*, as glass, &c. attract and retain it strongest, and contain the greatest quantity. This latter position may seem a paradox to some, being contrary to the hitherto received opinion; and therefore I shall now endeavour to explain it.

28. In

28. In order to this, let it first be consider'd, *that we cannot by any means we are yet acquainted with, force the electrical fluid thro' glass.* I know it is commonly thought that it easily prevades glass, and the experiment of a feather suspended by a thread in a bottle hermetically sealed, yet moved by bringing a rubbed tube near the outside of the bottle, is alledged to prove it. But, if the electrical fluid so easily pervades glass, how does the vial become *charged* (as we term it) when we hold it in our hands? Would not the fire thrown in by the wire pass through to our hands, and so escape into the floor? Would not the bottle in that case be left just as we found it, uncharged, as we know a metal bottle so attempted to be charged would be? Indeed, if there be the least crack, the minutest solution of continuity in the glass, though it remains so tight that nothing else we know of will pass, yet the extremely subtile electrical fluid flies through such a crack with the greatest freedom, and such a bottle we know can never be charged: What then makes the difference between such a bottle and one that is sound, but this, that the fluid can pass through the one, and not through the other? *

29. It is true there is an experiment that at first sight would be apt to satisfy a slight observer, that the fire thrown into the bottle by the wire, does really pass thro'

* See the first sixteen Sections of the former Paper, called *Farther Experiments*, &c.

the glass. It is this : place the bottle on a glass stand, under the prime conductor : suspend a bullet by a chain from the prime conductor ; till it comes within a quarter of an inch right over the wire of the bottle ; place your knuckle on the glass stand, at just the same distance from the coating of the bottle, as the bullet is from its wire. Now let the globe be turned, and you see a spark strike from the bullet to the wire of the bottle, and the same instant you see and feel an exactly equal spark striking from the coating on your knuckle, and so on spark for spark. This looks as if the whole received by the bottle was again discharged from it. And yet the bottle by this means is charged ! * And therefore the fire that thus leaves the bottle, though the same in quantity, cannot be the very same fire that entered at the wire ; for if it were, the bottle would remain uncharged.

30. If the fire that so leaves the bottle be not the same that is thrown in through the wire, it must be fire that subsisted in the bottle, (that is, in the glass of the bottle) before the operation began.

31. If so, there must be a great quantity in glass, because a great quantity is thus discharged even from very thin glass.

32. That this electrical fluid or fire is strongly attracted by glass, we know from the quickness and violence with which it is resumed by the part that had been deprived of

it, when there is an opportunity. And by this, that we cannot from a mass of glass draw a quantity of electrical fire, or electrify the whole mass *minus*, as we can a mass of metal. We cannot lessen or increase its whole quantity, for the quantity it has it holds; and it has as much as it can hold. Its pores are filled with it as full as the mutual repellency of the particles will admit; and what is already in, refuses, or strongly repels, any additional quantity. Nor have we any way of moving the electrical fluid in glass, but one; that is, by covering part of the two surfaces of thin glass with non-electrics, and then throwing an additional quantity of this fluid on one surface, which spreading in the non-electric and being bound by it to that surface, acts by its repelling force on the particles of the electrical fluid contained in the other surface, and drives them out of the glass into the non-electric on that side, from whence they are discharged, and then those added on the charged side can enter. But when this is done, there is no more in the glass, nor less than before, just as much having left it on one side as it received on the other.

33. I feel a want of terms here, and doubt much whether I shall be able to make this part intelligible. By the word *surface*, in this case, I do not mean mere length and breadth without thickness; but when I speak of the upper or under surface of a piece of glass, the outer or inner surface of the vial, I mean length, breadth, and half the thickness, and beg the favour of being so understood. Now, I suppose, that glass in its first principles, and in the
furnace,

Furnace, has no more of this electrical fluid than other common matter : That when it is blown, as it cools, and the particles of common fire leave it, its pores become a vacuum : That the component parts of glass are extremely small and fine, I guess from its never showing a rough face when it breaks, but always a polish ; and from the smallness of its particles I suppose the pores between them must be exceeding small, which is the reason that Aqua-fortis, nor any other menstruum we have, can enter to separate them and dissolve the substance ; nor is any fluid we know of, fine enough to enter, except common fire, and the electrical fluid. Now the departing fire leaving a vacuum, as aforesaid, between these pores, which air nor water are fine enough to enter and fill, the electrical fluid (which is every where ready in what we call the non-electrics, and in the non-electric Mixtures that are in the air,) is attracted in : yet does not become fixed with the substance of the glass, but subsists there as water in a porous stone, retained only by the attraction of the fixed parts, itself still loose and a fluid. But I suppose farther, that in the cooling of the glass, its texture becomes closest in the middle, and forms a kind of partition, in which the pores are so narrow, that the particles of the electrical fluid, which enter both surfaces at the same time, cannot go through, or pass and repass from one surface to the other, and so mix together ; yet, though the particles of electrical fluid, imbibed by each surface, cannot themselves

L

pass

pass through to those of the other, their repellency can, and by this means they act on one another. The particles of the electrical fluid have a mutual repellency, but by the power of attraction in the glass they are condensed or forced nearer to each other. When the glass has received, and, by its attraction, forced closer together so much of this electrified fluid, as that the power of attracting and condensing in the one, is equal to the power of expansion in the other, it can imbibe no more, and that remains its constant whole quantity; but each surface would receive more, if the repellency of what is in the opposite surface did not resist its entrance. The quantities of this fluid in each surface being equal, their repelling action on each other is equal; and therefore those of one surface cannot drive out those of the other: but, if a greater quantity is forced into one surface than the glass would naturally draw in; this encreases the repelling power on that side, and overpowering the attraction on the other, drives out part of the fluid that had been imbibed by that surface, if there be any non-electric ready to receive it: such there is in all cases where glass is electrified to give a shock. The surface that has been thus emptied by having its electrical fluid driven out, resumes again an equal quantity with violence, as soon as the glass has an opportunity to discharge that over-quantity more than it could retain by attraction in its other surface, by the additional repellency of which the vacuum had been occasioned. For experiments favouring

vouring (if I may not say confirming) this hypothesis, I must, to avoid repetition, beg leave to refer you back to what is said of the electrical phial in my former papers.

34. Let us now see how it will account for several other appearances.—Glass, a body extremely elastic (and perhaps its elasticity may be owing in some degree to the subsisting of so great a quantity of this repelling fluid in its pores) must, when rubbed, have its rubbed surface somewhat stretched, or its solid parts drawn a little farther asunder, so that the vacancies in which the electrical fluid resides, become larger, affording room for more of that fluid, which is immediately attracted into it from the cushion or hand rubbing, they being supply'd from the common stock. But the instant the parts of the glass so open'd and fill'd have pass'd the friction, they close again, and force the additional quantity out upon the surface, where it must rest till that part comes round to the cushion again, unless some non electric (as the prime conductor) first presents to receive it*. But if the inside of the globe be lined with a non-electric, the ad-

* In the dark the electrical fluid may be seen on the cushion in two semi-circles or half-moons, one on the fore part, the other on the back part of the cushion, just where the globe and cushion separate. In the fore crescent the fire is passing out of the cushion into the glass; in the other it is leaving the glass, and returning into the back part of the cushion. When the prime conductor is apply'd to take it off the glass, the back crescent disappears.

ditional repellency of the electrical fluid, thus collected by friction on the rubb'd part of the globe's outer surface, drives an equal quantity out of the inner surface into that non-electric lining, which receiving it, and carrying it away from the rubb'd part into the common mass, through the axis of the globe and frame of the machine, the new collected electrical fluid can enter and remain in the outer surface, and none of it (or a very little) will be received by the prime conductor. As this charg'd part of the globe comes round to the cushion again, the outer surface delivers its overplus fire into the cushion, the opposite inner surface receiving at the same time an equal quantity from the floor. Every electrician knows that a globe wet within will afford little or no fire, but the reason has not before been attempted to be given, that I know of.

34. So if a tube lined with a † non-electric, be rubb'd, little or no fire is obtained from it. What is collected from the hand in the downward rubbing stroke, entering the pores of the glass, and driving an equal quantity out of the inner surface into the non-electric lining: and the hand in passing up to take a second stroke, takes out again what had been thrown into the outer surface, and then the inner surface receives back again what it had given to the non-electric lining. Thus the particles of

† Gilt paper, with the gilt face next the glass, does well.

electrical fluid belonging to the inside surface go in and out of their pores every stroke given to the tube. Put a wire into the tube, the inward end in contact with the non-electric lining, so it will represent the *Leyden* bottle. Let a second person touch the wire while you rub, and the fire driven out of the inward surface when you give the stroke, will pass through him into the common mass, and return through him when the inner surface resumes its quantity, and therefore this new kind of *Leyden* bottle cannot so be charged. But thus it may : after every stroke, before you pass your hand up to make another, let the second person apply his finger to the wire, take the spark, and then withdraw his finger ; and so on till he has drawn a number of sparks ; thus will the inner surface be exhausted, and the outer surface charged ; then wrap a sheet of gilt paper close round the outer surface, and grasping it in your hand you may receive a shock by applying the finger of the other hand to the wire : for now the vacant pores in the inner surface resume their quantity, and their overcharg'd pores in the outer surface discharge that overplus ; the equilibrium being restored through your body, which could not be restored through the glass.* If the tube be exhausted of air, a non electric lining in contact with the wire is not necessary ; for *in vacuo*, the electrical fire will fly freely from

* See farther experiments, § 15.

the inner surface, without a non-electric conductor: but air resists its motion; for being itself an electric *per se*, it does not attract it, having already its quantity. So the air never draws off an electric atmosphere from any body, but in proportion to the non-electrics mix'd with it: it rather keeps such an atmosphere confin'd, which from the mutual repulsion of its particles, tends to dissipation, and would immediately dissipate *in vacuo*.—And thus the experiment of the feather inclosed in a glass vessel hermetically sealed, but moving on the approach of the rubbed tube, is explained: When an additional quantity of the electrical fluid is applyed to the side of the vessel by the atmosphere of the tube a quantity is repelled and driven out of the inner surface of that side into the vessel, and there affects the feather, returning again into its pores, when the tube with its atmosphere is withdrawn; not that the particles of that atmosphere did themselves pass through the glass to the feather.—And every other appearance I have yet seen, in which glass and electricity are concern'd, are, I think, explain'd with equal ease by the same hypothesis. Yet, perhaps, it may not be a true one, and I shall be obliged to him that affords me a better.

35. Thus I take the difference between non electrics and glass, an electric *per se*, to consist in these two particulars. 1st, That a non-electric easily suffers a change in the quantity of the electrical fluid it contains. You may

may lessen its whole quantity by drawing out a part, which the whole body will again resume; but of glass you can only lessen the quantity contain'd in one of its surfaces; and not that, but by supplying an equal quantity at the same time to the other surface; so that the whole glass may always have the same quantity in the two surfaces, their two different quantities being added together. And this can only be done in glass that is thin; beyond a certain thickness we have yet no power that can make this change. And, 2dly, that the electrical fire freely removes from place to place, in and through the substance of a non-electric, but not so through the substance of glass. If you offer a quantity to one end of a long rod of metal, it receives it, and when it enters, every particle that was before in the rod, pushes its neighbour quite to the further end, where the overplus is discharg'd; and this instantaneously where the rod is part of the circle in the experiment of a shock. But glass, from the smallness of its pores, or stronger attraction of what it contains, refuses to admit so free a motion; a glass rod will not conduct a shock, nor will the thinnest glass suffer any particle entering one of its surfaces to pass thro' to the other.

36. Hence we see the impossibility of success, in the experiments propos'd, to draw out the effluvial virtues of a non-electric, as cinnamon for instance, and mixing them with the electrical fluid, to convey them with that into
the

the body, by including it in the globe, and then applying friction, &c. For though the effluvia of cinnamon, and the electrical fluid should mix within the globe, they would never come out together through the pores of the glass, and so go to the prime conductor; for the electrical fluid itself cannot come through; and the prime conductor is always supply'd from the cushion, and that from the floor. And besides, when the globe is filled with cinnamon, or other non-electric, no electrical fluid can be obtain'd from its outer surface, for the reason before-mentioned. I have try'd another way, which I thought more likely to obtain a mixture of the electrical and other effluvia together, if such a mixture had been possible. I placed a glass plate under my cushion, to cut off the communication between the cushion and the floor; then brought a small chain from the cushion into a glass of oil of turpentine, and carried another chain from the oil of turpentine to the floor, taking care that the chain from the cushion to the glass touch'd no part of the frame of the machine. Another chain was fix'd to the prime conductor, and held in the hand of a person to be electrified. The ends of the two chains in the glass were near an inch distance from each other, the oil of turpentine between. Now the globe being turn'd, could draw no fire from the floor through the machine, the communication that way being cut off by the thick glass plate under the cushion: it must then draw it through the chains

chains whose ends were dipt in the oil of turpentine. And as the oil of turpentine being an electric *per se*, would not conduct what came up from the floor, was obliged to jump from the end of one chain, to the end of the other, through the substance of that oil, which we could see in large sparks; and so it had a fair opportunity of seizing some of the finest particles of the oil in its passage, and carrying them off with it: but no such effect followed, nor could I perceive the least difference in the smell of the electrical effluvia thus collected, from what it has when collected otherwise; nor does it otherwise affect the body of a person electrified. I likewise put into a phial, instead of water, a strong purgative liquid, and then charged the phial, and took repeated shocks from it, in which case every particle of the electrical fluid must, before it went through my body, have first gone through the liquid when the phial is charging, and returned through it when discharging, yet no other effect followed than if it had been charged with water. I have also smelt the electrical fire when drawn through gold, silver, copper, lead, iron, wood, and the human body, and could perceive no difference; the odour is always the same where the spark does not burn what it strikes; and therefore I imagine it does not take that smell from any quality of the bodies it passes through. And, indeed, as that smell so readily leaves the electrical matter, and adheres to the knuckle receiving the sparks, and to other

M

things;

things; I suspect that it never was connected with it, but arises instantaneously from something in the air acted upon by it. For if it was fine enough to come with the electrical fluid through the body of one person, why should it stop on the skin of another?

But I shall never have done, if I tell you all my conjectures, thoughts, and imaginations, on the nature and operations of this electrical fluid, and relate the variety of little experiments we have try'd. I have already made this paper too long, for which I must crave pardon, not having now time to make it shorter. I shall only add, that as it has been observed here that spirits will fire by the electrical spark in the summer time, without heating them, when *Fahrenheit's* thermometer is above 70; so, when colder, if the operator puts a small flat bottle of spirits in his bosom, or a close pocket, with the spoon, some little time before he uses them, the heat of his body will communicate warmth more than sufficient for the purpose.

ADDITI-

ADDITIONAL EXPERIMENT, *proving that the Leyden Bottle has no more electrical Fire in it when charged, than before; nor less when discharged: That in discharging, the Fire does not issue from the Wire and the Coating at the same Time, as some have thought, but that the Coating always receives what is discharged by the Wire, or an equal Quantity; the outer Surface being always in a negative State of Electricity, when the inner Surface is in a positive State.*

PLACE a thick plate of glass under the rubbing cushion, to cut off the communication of electrical fire from the floor to the cushion; then, if there be no fine points or hairy threads sticking out from the cushion, or from the parts of the machine opposite to the cushion, (of which you must be careful) you can get but a few sparks from the prime conductor, which are all the cushion will part with.

Hang a phial then on the prime conductor, and it will not charge, tho' you hold it by the coating.—But

Form a communication by a chain from the coating to the cushion, and the phial will charge.

For the globe then draws the electrical fire out of the outside surface of the phial, and forces it, through the prime conductor and wire of the phial, into the inside surface.

Thus the bottle is charged with its own fire, no other being to be had while the glass plate is under the cushion.

Hang two cork balls by flaxen threads to the prime conductor; then touch the coating of the bottle, and they will be electrified and recede from each other.

For just as much fire as you give the coating, so much is discharged through the wire upon the prime conductor, whence the cork balls receive an electrical atmosphere: But

Take a wire bent in the form of a C, with a stick of wax fixed to the outside of the curve, to hold it by; and apply one end of this wire to the coating, and the other at the same time to the prime conductor, the phial will be discharged; and if the balls are not electrified before the discharge, neither will they appear to be so after the discharge, for they will not repel each other.

Now if the fire discharged from the inside surface of the bottle through its wire, remained on the prime conductor, the balls would be electrified and recede from each other.

If the phial really exploded at both ends, and discharged fire from both coating and wire, the balls would be *more* electrified and recede *farther*: for none of the fire can escape, the wax handle preventing.

But if the fire, with which the inside surface is furcharged, be so much, precisely as is wanted by the outside surface, it will pass round through the wire fixed to the wax

handle

handle, restore the equilibrium in the glass, and make no alteration in the state of the prime conductor.

Accordingly we find, that if the prime conductor be electrified, and the cork balls in a state of repellency before the bottle is charged, they continue so afterwards. If not, they are not electrified by that discharge,

CORRECTIONS *and* ADDITIONS *to the* PRECEDING PAPERS.

PAGE 2, Sect. 1. We since find, that the fire in the bottle is not contained in the non-electric, but *in the glass*. All that is after said of the *top* and *bottom* of the bottle, is true of the *inside* and *outside* surfaces, and should have been so expressed. See Sect. 16, p. 16.

Page 6, Line 13. The equilibrium will soon be restored *but silently*, &c. This must have been a mistake. When the bottle is full charged, the crooked wire cannot well be brought to touch the top and bottom so quick, but that there will be a loud spark; unless the points be sharp without loops.

Ibid. line ult. *Outside*: add, such moisture continuing up to the cork or wire.

Page 12, line 14. *By candle-light* &c. From some observations since made, I am inclined to think, that it is not the light, but the smoke or non-electric effluvia from
the

the candle, coal, and red-hot iron, that carry off the electrical fire, being first attracted and then relepe'd.

Page 13, line 15. *Windmil wheels, &c.* We afterwards discovered, that the afflux or efflux of the electrical fire, was not the cause of the motions of those wheels, but various circumstances of attraction and repulsion.

Page 16, line 21. *Let A and B stand on wax, &c.* We soon found that it was only necessary for one of them to stand on wax.

Page 24, line 12. r. contact, line 24. confined.

Page 25, line 10. for *stand r. hand.*

Page 28, line 2. *The consequence might perhaps be fatal, &c.* We have found it fatal to small animals, but 'tis not strong enough to kill large ones. The biggest we have killed is a hen.

31, line 20. *Ringing of chimes, &c.* This is since done

Page 33, line 22. *Fails after ten or twelve experiments.* This was by a small bottle. And since found to fail after after with a large glass.

Page 40, sect. 50, 51. *Spirits must be heated before we can fire them, &c.* We have since fir'd spirits without heating, when the weather is warm.

- 31998 -

March 1957

- A. Davidson -

F I N I S.

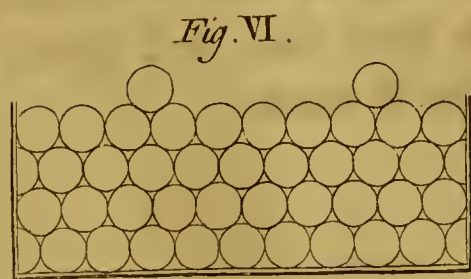
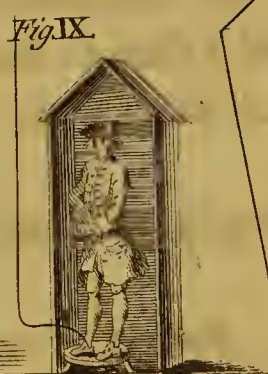
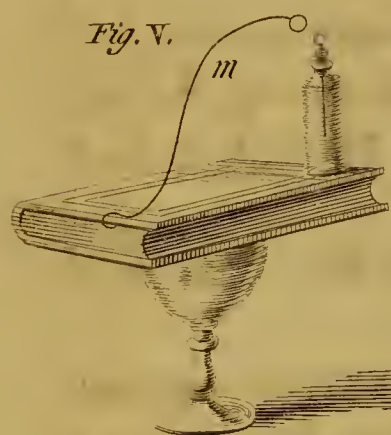
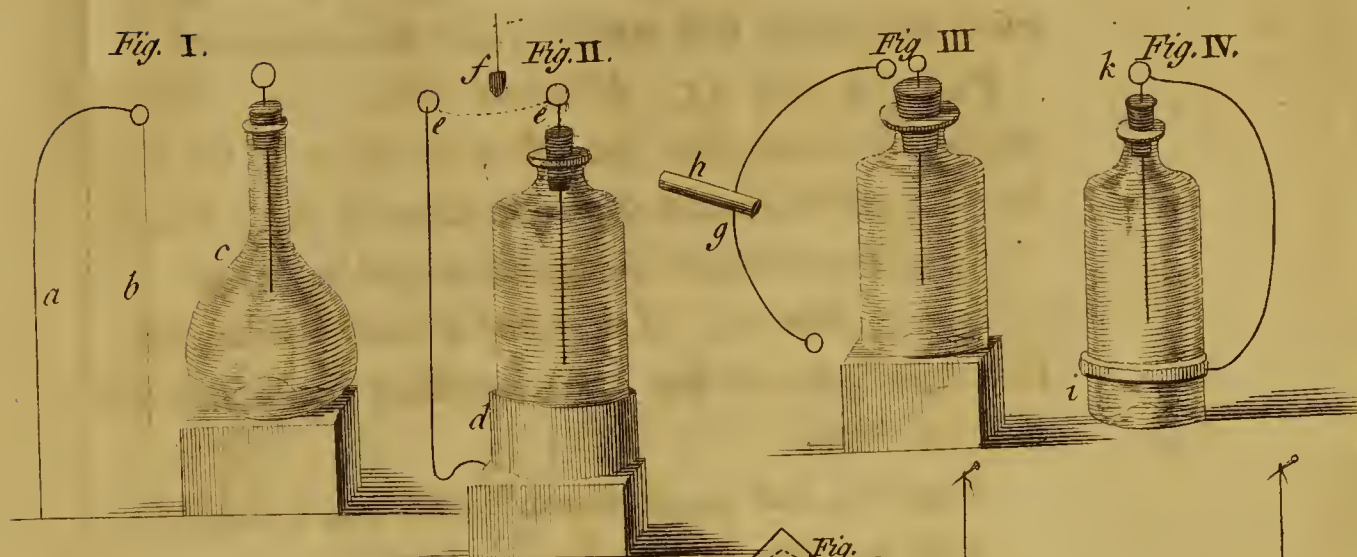


Fig. VII.

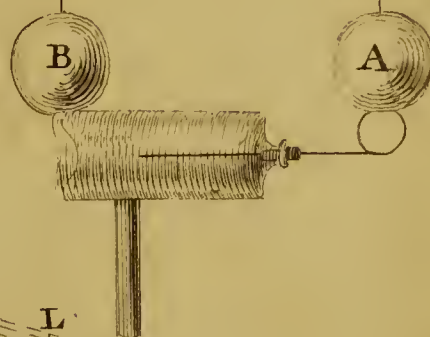
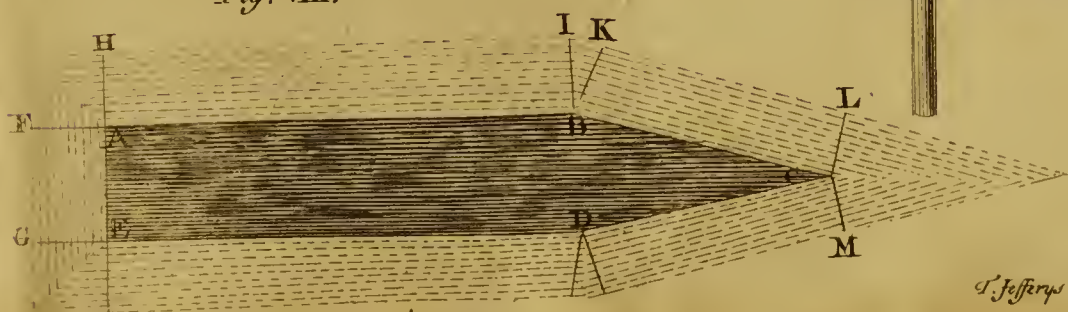


Fig. VIII.



T. Jefferys Sculp.

RPJCE

NEW EXPERIMENTS
AND
OBSERVATIONS
ON
ELECTRICITY.
MADE AT

Philadelphia in America.

BY
BENJAMIN FRANKLIN, *Esq;*

AND

Communicated in several Letters to P. COLLINSON, *Esq;*
of *London*, F.R.S.

PART II.

The SECOND EDITION.

L O N D O N:

Printed and sold by D. HENRY, and R. CAVE, at *St*
John's-Gate. 1754. (Price 6 *d.*)

RPJCB

LETTER V.

FROM

BENJAMIN FRANKLIN, *Esq*; of *Philadelphia*,

TO

PETER COLLINSON, *Esq*; F. R. S. at *London*.

S I R,

July 27, 1750.

MR. *W-tf-n*, I believe, wrote his observations on my last paper in haste, without having first well considered the experiments related in §. 17. which still appear to me decisive in the question, — *Whether the accumulation of the electrical fire be in the electrified glass, or in the non-electric matter connected with the glass?* And to demonstrate that 'tis really in the glass.

As to the experiment that ingenious gentleman mentions, and which he thinks conclusive on the other side, I persuade myself he will change his opinion of it, when he considers, that as one person applying the wire of the charged bottle to warm spirits, in a spoon held by another person, both standing on the floor, will fire the spirits, and yet such firing will not determine whether the accumula-

N

tion

tion was in the glass or the non-electric ; so the placing another person between them, standing on wax, with a basin in his hand, into which the water from the phial is pour'd, *while he at the instant of pouring* presents a finger of his other hand to the spirits, does not at all alter the case ; the stream from the phial, the side of the basin, with the arms and body of the person on the wax, being all together but as one long wire, reaching from the internal surface of the phial to the spirits.

June 29, 1751. In Capt. *Waddel's* account of the effects of lightening on his ship, I could not but take notice of the large comazants (as he calls them) that settled on the spintles at the topmast heads, and burnt like very large torches (before the stroke). According to my opinion, the electrical fire was then drawing off, as by points, from the cloud ; the largeness of the flame betokening the great quantity of electricity in the cloud : and had there been a good wire communication from the spintle heads to the sea, that could have conducted more freely than tarred ropes, or masts of turpentine wood, I imagine there would either have been no stroke ; or, if a stroke, the wire would have conducted it all into the sea without damage to the ship.

His compasses lost the virtue of the load-stone, or the poles were revers'd ; the North point turning to the South. — By electricity we have (*here at Philadelphia*) frequently given polarity to needles, and reversed them at pleasure.

Mr

Mr *Wilson*, at *London*, tried it on too large masses, and with too small force.

A shock from four large glass jars, sent through a fine sewing needle, gives it polarity, and it will traverse when laid on water.—If the needle when struck lies East and West, the end enter'd by the electric blast points North.—If it lies North and South, the end that lay towards the North will continue to point North when placed on water, whether the fire enter'd at that end or at the contrary end.

The polarity given is strongest when the needle is struck, lying North and South, weakest when lying East and West; perhaps if the force was still greater, the South end, enter'd by the fire, (when the needle lies North and South) might become the North, otherwise it puzzles us to account for the inverting of compasses by lightening; since their needles must always be found in that situation, and by our little experiments, whether the blast entered the North and went out at the South end of the needle, or the contrary, still the end that lay to the North should continue to point North.

In these experiments the ends of the needles are sometimes finely blued like a watch spring by the electric flame.—This colour given by the flash from two jars only, will wipe off, but four jars fix it, and frequently melt the needles. I send you some that have had their heads and points melted off, by our mimic lightening; and a pin that had its point melted off, and some part of its head

and neck run. Sometimes the surface on the body of the needle is also run, and appears blister'd when examin'd by a magnifying glass: the jars I make use of hold 7 or 8 gallons, and are coated and lined with tin foil; each of them takes a thousand turns of a globe nine inches diameter to charge it.

I send you two specimens of tin foil melted between glass, by the force of two jars only.

I have not heard that any of your *European* electricians have hitherto been able to fire gunpowder by the electric flame.—We do it here, in this manner.—A small cartridge is filled with dry powder, hard rammed, so as to bruise some of the grains, two pointed wires are then thrust in, one at each end, the points approaching each other in the middle of the cartridge till within the distance of half an inch, then the cartridge being placed in the circle, when the four jars are discharged, the electric flame leaping from the point of one wire to the point of the other, within the cartridge amongst the powder, *fires it*, and the explosion of the powder is at the same instant with the crack of the discharge.

I am, &c.

B. FRANKLIN.

LET-

LETTER VI.

FROM

BENJ. FRANKLIN, *Esq*; of *Philadelphia*,

TO

C. C. *Esq*; at *New York*.

S I R,

1751.

I Inclose you Answers, such as my present hurry of business will permit me to make, to the principal queries contain'd in yours of the 28th instant, and beg leave to refer you to the latter piece in the printed collection of my papers, for farther explanation of the difference between what are called *electrics per se* and *non electrics*. When you have had time to read and consider those papers, I will endeavour to make any new experiments you shall propose, that you think may afford farther light or satisfaction to either of us; and shall be much oblig'd to you for such remarks, objections, &c. as may occur to you.—I forget whether I wrote you that I have melted brass pins, and steel needles, inverted the poles of the magnetic needle, given a magnetism and polarity to
needles

needles that had none, and fired dry gunpowder by the electric spark. I have five bottles that contain 8 or 9 gallons each, two of which charg'd, are sufficient for those purposes; but I can charge and discharge them all together. There are no bounds (but what expence and labour give) to the force man may raise and use in the electrical way: For bottle may be added to bottle in infinitum, and all united and discharged together as one, the force and effect proportioned to their number and size. The greatest known effects of common lightening, may, I think, without much difficulty be exceeded in this way, which a few years since could not have been believed, and even now may seem to many a little extravagant to suppose.—So we are got beyond the skill of *Rabelais's* devils of two years old, who, he humourously says, had only learnt to thunder and lighten a little round the head of a cabbage.

I am, with sincere respect,

Your most obliged humble servant,

B. FRANKLIN.

Que-

Queries and Answers, *referr'd to in the foregoing Letter.*

Query. Wherein consists the difference between an *electric* and a *non-electric* body?

Answer. The terms *electric per se*, and *non-electric* were first used to distinguish bodies, on a mistaken supposition that those called *electrics per se* alone contain'd electric matter in their substance, which was capable of being excited by friction, and of being produced or drawn from them and communicated to those called *non-electrics*, supposed to be destitute of it: For the glass, &c. being rubbed, discover'd signs of having it, by snapping to the finger, attracting, repelling, &c. and could communicate those signs to metals and water.—Afterwards it was found, that rubbing of glass would not produce the electric matter, unless a communication was preserv'd between the rubber and the floor; and subsequent experiments prov'd that the electric matter was really drawn from those bodies that at first were thought to have none in them. Then it was doubted whether glass and other bodies called *electrics per se* had really any electric matter in them, since they apparently afforded none but what they first extracted from those which had been called *non-electrics*. But some of my experiments shew that glass contains it in great quantity, and I now suspect it to be pretty equally diffused in all the matter of this terraqueous globe

globe. If so, the terms *electric per se*, and *non electric*, should be laid aside as improper: And (the only difference being this, that some bodies will conduct electric matter, and others will not) the terms *conductors* and *non-conductors* may supply their place. If any portion of electric matter is applied to a piece of conducting matter, it penetrates and flows through it, or spreads equally on its surface; if applied to a piece of non-conducting matter, it will do neither. Perfect conductors of electric matter are only metals and water; other bodies conducting only as they contain a mixture of those; without more or less of which, they will not conduct at all.* This (by the way) shews a new relation between metals and water heretofore unknown.

To illustrate this by a comparison, which, however, can only give a faint resemblance. Electric matter passes through conductors as water passes through a porous stone, or spreads on their surfaces as water spreads on a wet stone; but when apply'd to non-conductors, 'tis like water dropt on a greasy stone; it neither penetrates, passes through, nor spreads on the surface, but remains in drops where it falls. See farther on this head in my last printed piece.

Query. What are the effects of air in electrical experiments?

Answer. All I have hitherto observed are these. Moist
air

*This proposition is since found to be too general; Mr *Wilson* having discovered that melted wax and rosin will also conduct.

air receives and conducts the electrical matter in proportion to its moisture, quite dry air not at all: air is therefore to be class'd with the non-conductors. Dry air assists in confining the electrical atmosphere to the body it surrounds, and prevents its dissipating: for in vacuo it quits easily, and points operate stronger, *i. e.* they throw off or attract the electrical matter more freely, and at greater distances; so that air intervening obstructs its passing from body to body, in some degree. A clean electrical phial and wire, containing air instead of water, will not be charged nor give a shock, any more than if it was fill'd with powder of glass; but exhausted of air it operates as well as if fill'd with water. Yet, an electrical atmosphere and air do not seem to exclude each other, for we breathe freely in such an atmosphere, and dry air will blow through it without displacing or driving it away. I question whether the strongest dry N. Wester would dissipate it. I once electrified a large cork ball, at the end of a silk thread 3 feet long, the other end of which I held in my fingers, and whirl'd it round, like a sling, 100 times in the air, with the swiftest motion, I could possibly give it, yet it retain'd its electrical atmosphere, though it must have pass'd through 800 yards of air, allowing my arm in giving the motion to add a foot to the semidiameter of the circle.—By quite dry air, I mean the dryest we have: for perhaps we never have any perfectly free from moisture. An electrical atmosphere raised round a thick wire, inserted in a phial of air, drives out none of the air, nor

on withdrawing that atmosphere will any air rush in, as I have found by a very curious experiment, accurately made, whence we concluded that the air's elasticity was not affected thereby.

An Experiment towards discovering more of the Qualities of the Electric Fluid.

FROM the prime conductor, hang a bullet by a wire hook ; under the bullet at half an inch distance, place a bright piece of silver to receive the sparks ; then let the wheel be turned, and in a few minutes (if the repeated sparks continually strike in the same spot) the silver will receive a blue stain near the colour of a watch spring.

A bright piece of iron will also be spotted, but not with that colour ; it rather seems corroded.

On gold, brass, or tin, I have not perceived that it makes any impression. But the spots on the silver or iron will be the same, whether the bullet be lead, brass, gold, or silver.

On a silver bullet, there will also appear a small spot, as well as on the plate below it.

L E T T E R VII.

F R O M

Mr E. KINNERSLEY, at *Boston*,

T O

BENJAMIN FRANKLIN, Esq; at *Philadelphia*.

S I R,

Feb. 3, 1752.

I Have the following experiments to communicate: I held in one hand a wire, which was fasten'd at the other end to the handle of a pump, in order to try whether the stroke from the prime conductor, through my arms, would be any greater, than when convey'd only to the surface of the earth, but could discover no difference.

I placed the needle of a compass on the point of a long pin, and holding it in the atmosphere of the prime conductor, at the distance of about three inches, found it to whirl round, like the flyers of a jack, with great rapidity.

I suspended with silk, a cork ball, about the bigness of a pea, and presented to it, rubbed amber, sealing wax, and sulphur, by each of which it was strongly repelled;

O 2

then

then I tried rubbed glass and china, and found that each of these would attract it, until it became electrified again, and then it would be repelled as at first; and while thus repelled by the rubbed glass or china, either of the others when rubbed would attract it. Then I electrified the ball, with the wire of a charged phial, and presented to it rubbed glass (the stopper of a decanter) and a china tea cup, by which it was as strongly repelled, as by the wire; but when I presented either of the other rubbed electrics, it would be strongly attracted, and when I electrified it, by either of these, till it became repelled, it would be attracted by the wire of the phial, but be repelled by its coating

These experiments surprized me very much, and have induced me to infer the following paradoxes.

1. If a glass globe be placed at one end of a prime conductor, and a sulphur one at the other end, both being equally in good order, and in equal motion, not a spark of fire can be obtain'd from the conductor; but one globe will draw out, as fast as the other gives in.

2. If a phial be suspended on the conductor, with a chain from its coating to the table, and only one of the globes be made use of at a time, 20 turns of the wheel, for instance, will charge it; after which, so many turns of the other wheel will discharge it; and as many more will charge it again.

3. The globes being both in motion, each having a separate conductor, with a phial suspended on one of them,
and

and the chain of it fastned to the other, the phial will become charged ; one globe charging positively, the other negatively.

4. The phial being thus charged, hang it in like manner on the other conductor ; set both wheels a going again, and the same number of turns that charged it before, will now discharge it ; and the same number repeated, will charge it again.

5. When each globe communicates with the same prime conductor, having a chain hanging from it to the table, one of them, when in motion, (but which I can't say) will draw fire up through the cushion, and discharge it through the chain ; the other will draw it up through the chain, and discharge it through the cushion.

I should be glad if you would send to my house for my sulphur globe, and the cushion belonging to it, and make the trial ; but must caution you not to use chalk on the cushion, some fine powdered sulphur will do better. If, as I expect, you should find the globes to charge the prime conductor differently, I hope you will be able to discover some method of determining which it is that charges positively.

I am, &c.

E. KINNERSLEY.

LET-

LETTER VIII.

FROM

BENJAMIN FRANKLIN, *Esq*; of *Philadelphia*,

TO

Mr E. KINNERSLEY, at *Boston*.

S I R,

March 2, 1752.

I Thank you for the experiments communicated. I sent immediately for your brimstone globe, in order to make the trials you desired, but found it wanted centers, which I have not time now to supply; but the first leisure I will get it fitted for use, try the experiments, and acquaint you with the result.

In the mean time I suspect, that the different attractions and repulsions you observed, proceeded rather from the greater or smaller quantities of the fire you obtained from different bodies, than from its being of a different *kind*, or having a different *direction*. In haste

I am, &c.

B. FRANKLIN.

LET-

L E T T E R IX.

F R O M

BENJ. FRANKLIN, *Esq*; of *Philadelphia*,

T O

Mr E. KINNERSLEY, at *Boston*.*S I R,**March 16, 1752.*

HAVING brought your brimstone globe to work, **I**
I try'd one of the experiments you propos'd,
and was agreeably surprized to find, that the
glass globe being at one end of the conductor, and the
sulphur globe at the other end, both globes in motion, no
spark could be obtain'd from the conductor, unless when
one globe turned slower, or was not in so good order as
the other; and then the spark was only in proportion to
the difference, so that turning equally, or turning that
slowest which work'd best, would again bring the con-
ductor to afford no spark.

I found also, that the wire of a phial charg'd by the
glass globe, attracted a cork ball that had touch'd the wire
of a phial charged by the brimstone globe, and *vice versa*,
so

so that the cork continued to play between the two phials, just as when one phial was charged through the wire, the other through the coating, by the glass globe alone. And two phials charged, the one by the brimstone globe, the other by the glass globe, would be both discharged by bringing their wires together, and shock the person holding the phials.

From these experiments, one may be certain that your 2d, 3d, and 4th proposed experiments, would succeed exactly as you suppose, though I have not tried them, wanting time. — I imagine it is the glass globe that charges positively, and the sulphur negatively, for these reasons, 1. Though the sulphur globe seems to work equally well with the glass one, yet it can never occasion so large and distant a spark between my knuckle and the conductor when the sulphur one is working, as when the glass one is used; which, I suppose, is occasioned by this, that bodies of a certain bigness cannot so easily part with a quantity of electrical fluid they have and hold attracted *within* their substance, as they can receive an additional quantity *upon* their surface by way of atmosphere. Therefore so much cannot be drawn *out* of the conductor, as can be thrown *on* it. 2. I observe that the stream or brush of fire appearing at the end of a wire connected with the conductor, is long, large, and much diverging, when the glass globe is used, and makes a snapping (or rattling) noise: but when the sulphur one is used, it is short, small, and makes a hissing noise; and just the reverse

verse of both happens, when you hold the same wire in your hand, and the globes are work'd alternately: the brush is large, long, diverging and snapping (or rattling) when the sulphur globe is turn'd; short small, and hissing, when the glass globe is turn'd.—When the brush is long, large, and much diverging, the body to which it joins, seems to me to be throwing the fire out; and when the contrary appears, it seems to be drinking in. 3. I observe, that when I held my knuckle before the sulphur globe, while turning, the stream of fire between my knuckle and the globe, seems to spread on its surface, as if it flow'd from the finger; on the glass globe 'tis otherwise. 4. The cool wind (or what was call'd so) that we used to feel as coming from an electrified point, is much more sensible, when the glass globe is used, than when the sulphur one.—But these are hasty thoughts. As to your 5th paradox, it must likewise be true, if the globes are alternately work'd; but if work'd together, the fire will neither come up nor go down by the chain, because one globe will drink it as fast as the other produces it.

I should be glad to know whether the effects would be contrary, if the glass globe is solid, and the sulphur globe hollow; but I have no means at present of trying.

In your journeys, your glass globes meet with accidents, and sulphur ones are heavy and inconvenient.

Query. Would not a thin plane of brimstone, cast on a board, serve on occasion as a cushion, while a globe of

P

leather

leather stuff'd (properly mounted) might receive the fire from the sulphur, and charge the conductor positively? Such a globe would be in no danger of breaking. I think I can conceive how it may be done; but have not time to add more than that I am,

Yours, &c.

B. FRANKLIN.

L E T T E R X.

F R O M

BENJ. FRANKLIN, *Esq*; of *Philadelphia*,

Oct. 19, 1752.

AS frequent mention is made in the news papers from *Europe*, of the success of the *Philadelphia* experiment for drawing the electric fire from clouds by means of pointed rods of iron erected on high buildings, &c. it may be agreeable to inform the curious that the same experiment has succeeded in *Philadelphia*, though made in a different and more easy manner, which is as follows :

Make a small cross of two light strips of cedar, the
arms

arms so long as to reach to the four corners of a large thin silk handkerchief when extended; tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite; which being properly accommodated with a tail, loop, and string, will rise in the air, like those made of paper; but this being of silk is fitter to bear the wind and wet of a thunder gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp pointed wire, rising a foot or more above the wood. To the end of the twine, next the hand, is to be ty'd a silk ribbon, and where the silk and twine join, a key may be fastened. This kite is to be raised when a thunder gust appears to be coming on, and the person who holds the string must stand within a door, or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and the loose filaments of the twine will stand out every way, and be attracted by an approaching finger. And when the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle. At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the
help

help of a rubbed glass globe or tube; and thereby the sameness of the electric matter with that of lightening completely demonstrated.

B. F.

LETTER XI.

FROM

BENJAMIN FRANKLIN, Esq; at *Philadelphia*.

AS you tell me our friend *Cave* is about to add some later experiments to my pamphlet, with the *Errata*, I send a copy of a letter from Dr *Colden* which may help to fill a few pages; also my kite experiment in the *Pennsylvania Gazette*: to which I have nothing new to add, except the following experiment towards discovering more of the qualities of the electric fluid. From the prime conductor, hang a bullet by a wire hook; under the bullet, at half an inch distance, place a bright piece of silver to receive the sparks; then let the wheel be turned, and in a few minutes (if the repeated sparks continually strike in the same spot) the silver will receive a blue stain, near the colour of a watch spring. A bright piece of iron will also be spotted, but
not

not with that colour : it rather seems to be corroded. On gold, brass, or tin, I have not perceived that it makes any impression. But the spots on the silver or iron will be the same, whether the bullet be lead, brass, gold, or silver. On a silver bullet there will also appear a small spot, as well as in the plate below it.

One Mr *Watts* promised in the *Magazine*, to write something on electricity ; I have not yet seen it advertised.

F I N I S.

ADDITIONAL ERRATA in PART I. to the printed
ELECTRICAL PAPERS. By B. FRANKLIN

PAGE 38, line 2. read, *represented by A and B,*
Fig. 6.

Page 40, line 7. r. *repulsion.*

Page 65, l. 19. r. *Aqua Regia.*

Page 70, l. 6. r. *rubbed.*

Fig. VI. in the plate, wants the referring letters A, B, C, D. In the copy that Fig. was mentioned as a profile of a piece of water, the little circles representing particles. The two upper circles were mark'd A and B, and two others in the under line or row C and D. As it stands 'tis wholly unintelligible.

Page 73, l. 17. r. *air.*

Page 74, l. 7. r. *electrical.*

Page 81, l. 3. place a *comma* at conduct, and dele *comma* at floor.

Page 85, l. 5. r. *discharged.* line 13. r. *p. 24.*

Page 86, l. 20. r. *after one.*

Copy 2
L_f

NEW EXPERIMENTS

A N D

OBSERVATIONS

O N

ELECTRICITY.

M A D E A T

Philadelphia in America.

B Y

BENJAMIN FRANKLIN, *Esq;*

Communicated to P. COLLINSON, *Esq;* of *London*, F.R.S.

And read at the Royal Society *June 27*, and *July 4*, 1754.

To which are added

A Paper on the same Subject by *J. Canton*, M.A. F.R.S. and read at the Royal Society *Dec. 6*, 1753; and another in defence of Mr *Franklin* against the Abbe *Nollet*, by Mr *D. Golden*, of *New York*.

P A R T I I I.

L O N D O N:

Printed and sold by D. HENRY, and R. CAVE, at *St John's-Gate*. 1754. (Price 1 s.)

NEW EXPLANATIONS

CONTENTS of the PART

CHAPTER I. OF THE NATURE AND EXTENT OF THE SUBJECT. 1

CHAPTER II. OF THE HISTORY OF THE SUBJECT. 2

CHAPTER III. OF THE PHYSICAL CAUSES OF THE SUBJECT. 3

CHAPTER IV. OF THE CHEMICAL CAUSES OF THE SUBJECT. 4

CHAPTER V. OF THE MEDICAL CAUSES OF THE SUBJECT. 5

CHAPTER VI. OF THE LEGAL CAUSES OF THE SUBJECT. 6

CHAPTER VII. OF THE POLITICAL CAUSES OF THE SUBJECT. 7

CHAPTER VIII. OF THE MORAL CAUSES OF THE SUBJECT. 8

CHAPTER IX. OF THE RELIGIOUS CAUSES OF THE SUBJECT. 9

CHAPTER X. OF THE SOCIAL CAUSES OF THE SUBJECT. 10

CHAPTER XI. OF THE ECONOMIC CAUSES OF THE SUBJECT. 11

CHAPTER XII. OF THE SCIENTIFIC CAUSES OF THE SUBJECT. 12

CHAPTER XIII. OF THE ARTS AND MANUFACTURES CAUSES OF THE SUBJECT. 13

CHAPTER XIV. OF THE MILITARY CAUSES OF THE SUBJECT. 14

CHAPTER XV. OF THE NAVAL CAUSES OF THE SUBJECT. 15

CHAPTER XVI. OF THE AGRICULTURAL CAUSES OF THE SUBJECT. 16

CHAPTER XVII. OF THE COMMERCE CAUSES OF THE SUBJECT. 17

CHAPTER XVIII. OF THE FINANCIAL CAUSES OF THE SUBJECT. 18

CHAPTER XIX. OF THE LEGISLATIVE CAUSES OF THE SUBJECT. 19

CHAPTER XX. OF THE JUDICIAL CAUSES OF THE SUBJECT. 20

CHAPTER XXI. OF THE EXECUTIVE CAUSES OF THE SUBJECT. 21

CHAPTER XXII. OF THE ADMINISTRATIVE CAUSES OF THE SUBJECT. 22

CHAPTER XXIII. OF THE EDUCATIONAL CAUSES OF THE SUBJECT. 23

CHAPTER XXIV. OF THE CULTURAL CAUSES OF THE SUBJECT. 24

CHAPTER XXV. OF THE RECREATIONAL CAUSES OF THE SUBJECT. 25

CHAPTER XXVI. OF THE DOMESTIC CAUSES OF THE SUBJECT. 26

CHAPTER XXVII. OF THE FOREIGN CAUSES OF THE SUBJECT. 27

CHAPTER XXVIII. OF THE INTERNATIONAL CAUSES OF THE SUBJECT. 28

CHAPTER XXIX. OF THE TRANSNATIONAL CAUSES OF THE SUBJECT. 29

CHAPTER XXX. OF THE SUPRANATIONAL CAUSES OF THE SUBJECT. 30

RRPICK

CONTENTS of all the PARTS.

LETTER I. From *Benjamin Franklin, Esq;* of *Philadelphia* to *Peter Collinson, Esq;* F.R.S. *London.* page 1.

— Observations on the *Leyden* Experiment, confirmed by further Experiments

LETTER II. From the same to the same page 10

— An Account of certain new electrical Phænomena; electrical Lightning; an electrical Kiss; an electrical Spider; a commodious Machine, &c.

LETTER III. From the same to the same p. 19

— Farther Experiments and Observations on Electricity. On the *Leyden* Phial; a magical Picture; a Wheel turning by Electricity; an electrical Jack; a self-moving Wheel; Paper perforated by electrical Fire, &c.

LETTER IV. Observations, &c. towards forming a new Hypothesis, for explaining the several Phænomena of Thunder-gusts p. 36.

ADDITIONAL PAPERS.

— Opinions and Conjectures concerning the Properties and Effects of the electrical Matter, arising from Experiments and Observations made in *Philadelphia* 1749 p. 51

— Additional Experiments concerning the *Leyden* Bottle p. 83

— Corrections and Additions to the preceding Papers p. 85

LETTER V. From Mr *Franklin* to Mr *Collinson* p. 89

— Commazants on Ship-board; Sea Compasses spoiled, or their Poles inverted by Lightning; Polarty given to Needles by Electricity, and the Needles turned blue thereby, and sometimes melted; as also Tin-foil; Gunpowder fired by electric Flame.

LETTER VI. From the same to the same p. 93

— Queries and Answers about Electrics and Non-electrics; the Effects of Air in electrical Experiments; Experiment towards discovering more of the Qualities of the electric Fluid

LETTER VII. From Mr *Kinnerfly* at *Boston* to *B. Franklin, Esq;* at *Philadelphia*; what glass repels, rosins and sulphurs attract; the Conductor refuses to be electrified by rubbed Glass and Sulphur applied to it at the same time; the Phial charged by the sulphur Globe, and then discharged by the Glass one, and *vice versa*, &c. p. 99

LETTER VIII. Mr *Franklin's* Answer to Mr *Kinnerfly* p. 102

LETTER IX. Mr *Franklin* to Mr *Kinnerfly*. Experiments with a Glass and Brimstone Globe; a Quere p. 103

LETTER

C O N T E N T S.

LETTER X. From the same to the same p. 106
 — Experiment of drawing the electric Fire from Clouds by pointed Iron Rods; an electrical Kite; how to draw Fire from Clouds with it; Bodies below electrified thereby, as with the usual Glass Machine

LETTER XI. From Mr *Franklin* to Mr *Collinson* p. 108
 — Silver turned blue by electric Effluvia

LETTER XII. From the same to the same p. 111
 — Of the luminous Appearance of Sea-water; how clouds become electrified; Experiments for shewing whether they are *negatively* or *positively* electrified; conjectures on this Occasion. What Thickness of a metallic rod best for drawing Lightning from the Clouds, and securing Edifices, &c.

LETTER XIII. From the same to the same p. 128
 — An account of Mr *Kinnerfley's* Experiments on the *positive* and *negative* State of Electricity in the Clouds.

Remarks on the Abbe *Nollet's* Letters on Electricity to *Benjamin Franklin Esq;* By Mr *David Colden*, of *New York* p. 130

Electrical Experiments, with an Attempt to account for their Phænomena; together with some Observations on Thunder Clouds; made in *London* about the same Time Mr *Franklin's* were carrying on in *America*; by *John Canton*, M. A. and F. R. S. 143

A P P E N D I X.

Mr *Franklin's* Account of his killing a Turkey by an electrical Shock; and of the Sensations which he felt himself upon receiving accidentally another violent electrical Shock, without Detriment p. 153

LET-

LETTER XII.

FROM

BENJ. FRANKLIN, *Esq;* of *Philadelphia*.

TO

PETER COLLINSON, *Esq;* F. R. S. *London*.

S I R,

Philadelphia, September 1753.

I N my former paper on this subject, wrote first in 1747, enlarged and sent to *England* in 1749, I considered the sea as the grand source of lightning; imagining its luminous appearance to be owing to electric fire, produc'd by friction between the particles of water and those of salt. Living far from the sea, I had then no opportunity of making experiments on the sea water, and so embrac'd this opinion too hastily.

For in 1750 and 1751, being occasionally on the sea coast, I found, by experiments, that sea water in a bottle, tho' at first it would by agitation appear luminous, yet in a few hours it lost that virtue; hence, and from this, that I could not by agitating a solution of sea salt in water pro-

Q

duce

duce any light, I first began to doubt of my former hypothesis, and to suspect that the luminous appearance in sea water must be owing to some other principles.

I then considered whether it were not possible, that the particles of air, being electrics *per se*, might, in hard gales of wind, by their friction against trees, hills, buildings, &c. as so many minute electric globes, rubbing against non-electric cushions, draw the electric fire from the earth; and that the rising vapours might receive that fire from the air, and by such means the clouds become electrified.

If this were so, I imagined that by forcing a constant violent stream of air against my prime conductor, by bellows, I should electrify it *negatively*; the rubbing particles of air, drawing from it part of its natural quantity of the electric fluid. I accordingly made the experiment, but it did not succeed.

In September 1752, I erected an iron rod to draw the lightning down into my house, in order to make some experiments on it, with two bells to give notice when the rod should be electrify'd: A contrivance obvious to every electrician.

I found the bells rang sometimes when there was no lightning or thunder, but only a dark cloud over the rod; that sometimes after a flash of lightning they would suddenly stop; and at other times, when they had not rang before, they would, after a flash, suddenly begin to ring; that the electricity was sometimes very faint, so that when

a small

a small spark was obtain'd, another could not be got for sometime after; at other times the sparks would follow extremely quick, and once I had a continual stream from bell to bell, the size of a crow-quill: Even during the same gulf there were considerable variations.

In the winter following I conceived an experiment, to try whether the clouds were electrify'd *positively*, or *negatively*; but my pointed rod, with its apparatus, becoming out of order, I did not refit it till towards the spring, when I expected the warm weather would bring on more frequent thunder-clouds.

The experiment was this: To take two phials; charge one of them with lightning from the iron rod, and give the other an equal charge by the electric glass globe, thro' the prime conductor: When charg'd, to place them on a table within three or four inches of each other, a small cork ball being suspended by a fine silk thread from the ceiling, so as it might play between the wires. If both bottles then were electrified *positively*, the ball being attracted and repell'd by one, must be also repell'd by the other. If the one *positively*, and the other *negatively*; then the ball would be attracted and repell'd alternately by each, and continue to play between them as long as any considerable charge remained.

Being very intent on making this experiment, it was no small mortification to me, that I happened to be abroad during two of the greatest thunder-storms we had early in the spring; and tho' I had given orders in my family, that

if the bells rang when I was from home, they should catch some of the lightning for me in electrical phials, and they did so; yet it was mostly dissipated before my return; and in some of the other gusts, the quantity of lightning I was able to obtain, was so small, and the charge so weak, that I could not satisfy myself: Yet I sometimes saw what heighten'd my suspicious and inflam'd my curiosity.

At last, on the 12th of *April* 1753, there being a smart gust of some continuance, I charg'd one phial pretty well with lightning, and the other equally, as near as I could judge, with electricity from my glass globe; and having plac'd them properly, I beheld, with great surprize and pleasure, the cork ball play briskly between them; and was convinc'd that one bottle was electrified *negatively*.

I repeated this experiment several times during the gust, and in eight succeeding gusts, always with the same success; and being of opinion (for reasons I formerly gave in my letter to Mr *Kinnerley*, since printed in *London*) that the glass globe electrifies *positively*; I concluded that the clouds are *always* electrified *negatively*, or have always in them less than their natural quantity of the electric fluid.

Yet notwithstanding so many experiments, it seems I concluded too soon; for at last, *June* the 6th, in a gust which continued from five o'clock, P. M. to 7, I met with one cloud that was electrified positively, tho' several that pass'd over my rod before, during the same gust, were in the negative state. This was thus discovered:

I had

I had another concurring experiment, which I often repeated, to prove the negative state of the clouds, *viz.* While the bells were ringing, I took the phial charg'd from the glass globe, and apply'd its wire to the erected rod; considering, that if the clouds were electrified *positively*, the rod, which received its electricity from them, must be so too; and then the additional *positive* electricity of the phial would make the bells ring faster:—But, if the clouds were in a *negative* state, they must exhaust the electric fluid from my rod, and bring that into the same negative state with themselves; and then the wire of a positively charg'd phial, supplying the rod with what it wanted (which it was oblig'd otherwise to draw from the earth by means of the pendulous brass ball playing between the two bells) the ringing would cease till the bottle was discharg'd.

In this manner I quite discharged into the rod several phials that were charged from the glass globe, the electric fluid streaming from the wire to the rod, 'till the wire would receive no spark from the finger; and during this supply to the rod from the phial, the bells stopt ringing; but by continuing the application of the phial wire to the rod, I exhausted the natural quantity from the inside surface of the same phials, or, as I call it, charg'd them *negatively*.

At length, while I was charging a phial by my glass globe, to repeat this experiment, my bells, of themselves, stopt ringing, and, after some pause, began to ring again.—But now, when I approached the wire of the charg'd

phial to the rod, instead of the usual stream that I expected from the wire to the rod, there was no spark; not even when I brought the wire and the rod to touch; yet the bells continued ringing vigorously; which prov'd to me, that the rod was then *positively* electrify'd, as well as the wire of the phial, and equally so; and consequently, that the particular cloud then over the rod, was in the same positive state. This was near the end of the gust.

But this was a single experiment, which however destroys my first too general conclusion, and reduces me to this: *That the clouds of a thunder-gust are most commonly in a negative state of electricity, but sometimes in a positive state.*

The latter I believe is rare; for tho' I soon after the last experiment, set out on a journey to *Boston*, and was from home most part of the summer, which prevented my making farther trials and observations; yet Mr *Kinnersley* returning from the islands just as I left home, pursu'd the experiments during my absence, and informs me that he always found the clouds in the *negative* state.

So that, for the most part, in thunder-strokes, 'tis *the earth that strikes into the clouds, and not the clouds that strike into the earth.*

Those who are vers'd in electric experiments, will easily conceive, that the effects and appearances must be nearly the same in either case; the same explosion, and the same flash between one cloud and another, and between the

clouds.

clouds and mountains, &c. the same rending of trees, walls, &c. which the electric fluid meets with in its passage, and the same fatal shock to animal bodies; and that pointed rods fix'd on buildings, or masts of ships, and communicating with the earth or sea, must be of the same service in restoring the equilibrium silently between the earth and clouds, or in conducting a flash or stroke, if one should be, so as to save harmless the house or vessel: For points have equal power to throw off, as to draw on the electric fire, and rods will conduct up as well as down.

But tho' the light gain'd from these experiments makes no alteration in the practice, it makes a considerable one in the theory. And now we as much need an hypothesis to explain by what means the clouds become negatively, as before to shew how they became positively electrified.

I cannot forbear venturing some few conjectures on this occasion: They are what occur to me at present; and tho' future discoveries should prove them not wholly right, yet they may in the mean time be of some use, by stirring up the curious to make more experiments, and occasion more exact disquisitions.

I conceive then, that this globe of earth and water, with its plants, animals and buildings, have, diffus'd throughout their substance, a quantity of the electric fluid, just as much as they can contain, which I call the *natural quantity*.

That this natural quantity is not the same in all kinds of common matter under the same dimensions, nor in the
same

same kind of common matter in all circumstances; but a solid foot, for instance, of one kind of common matter, may contain more of the electric fluid than a solid foot of some other kind of common matter; and a pound weight of the same kind of common matter may, when in a rarer state, contain more of the electric fluid than when in a denser state.

For the electric fluid, being attracted by any portion of common matter, the parts of that fluid (which have among themselves a mutual repulsion) are brought so near to each other by the attraction of the common matter that absorbs them, as that their repulsion is equal to the condensing power of attraction in common matter; and then such portion of common matter will absorb no more.

Bodies of different kinds having thus attracted and absorb'd what I call their *natural quantity*, *i. e.* just as much of the electric fluid as is suited to their circumstances of density, rarity, and power of attracting, do not then show any signs of electricity among each other.

And if more electric fluid be added to one of these bodies, it does not enter, but spreads on the surface, forming an atmosphere; and then such body shows signs of electricity.

I have in a former paper compar'd common matter to a sponge, and the electric fluid to water: I beg leave once more to make use of the same comparison, to illustrate farther my meaning in this particular.

When

When a sponge is somewhat condens'd by being squeez'd between the fingers, it will not receive and retain so much water as when in its more loose and open state.

If *more* squeez'd and condens'd, some of the water will come out of its inner parts, and flow on the surface.

If the pressure of the fingers be intirely removed, the sponge will not only resume what was lately forced out, but attract an additional quantity.

As the sponge in its rarer state will *naturally* attract and absorb *more* water, and in its denser state will *naturally* attract and absorb *less* water; we may call the quantity it attracts and absorbs in either state, its *natural quantity*, the state being considered.

Now what the sponge is to water, the same is water to the electric fluid.

When a portion of water is in its common dense state, it can hold no more electric fluid than it has; if any be added, it spreads on the surface.

When the same portion of water is rarify'd into vapour, and forms a cloud, it is then capable of receiving and absorbing a much greater quantity; there is room for each particle to have an electric atmosphere.

Thus water, in its rarify'd state, or in the form of a cloud, will be in a negative state of electricity; it will have less than its *natural quantity*; that is, less than it is naturally capable of attracting and absorbing in that state.

Such a cloud, then, coming so near the earth as to be within the striking distance, will receive from the earth a

R

flash

flash of the electric fluid; which flash, to supply a great extent of cloud, must sometimes contain a very great quantity of that fluid.

Or such a cloud, passing over woods of tall trees, may from the points and sharp edges of their moist top leaves, receive silently some supply.

A cloud being by any means supply'd from the earth, may strike into other clouds that have not been supply'd, or not so much supply'd; and those to others, till an equilibrium is produc'd among all the clouds that are within striking distance of each other.

The cloud thus supply'd, having parted with much of what it first receiv'd, may require and receive a fresh supply from the earth, or from some other cloud, which by the wind is brought into such a situation as to receive it more readily from the earth.

Hence repeated, and continual strokes and flashes till the clouds have all got nearly their natural quantity as clouds; or till they have descended in showers, and are united again with this terraqueous globe, their original.

Thus thunder-clouds are generally in a negative state of electricity compar'd with the earth, agreeable to most of our experiments; yet as by one experiment we found a cloud electrified positively; I conjecture that, in that case, such cloud, after having received what was, in its rare state, only its *natural quantity*, became compress'd by the driving winds, or some other means, so that part of what it had absorb'd was forc'd out, and form'd an electric atmosphere

mosphere around it in its denser state. Hence it was capable of communicating positive electricity to my rod.

To show that a body in different circumstances of dilatation and contraction is capable of receiving and retaining more or less of the electric fluid on its surface, I would relate the following experiment. I placed a clean wine glass on the floor, and on it a small silver can. In the can I put about three yards of brass chain; to one end of which I fastened a silk thread, which went right up to the ceiling, where it passed over a pulley, and came down again to my hand, that I might at pleasure draw the chain up out of the can, extending it till within a foot of the ceiling, and let it gradually sink into the can again.—From the ceiling, by another thread of fine raw silk, I suspended a small light lock of cotton, so as that when it hung perpendicularly, it came in contact with the side of the can.—Then approaching the wire of a charged vial to the can, I gave it a spark, which flow'd round it in an electric atmosphere; and the lock of cotton was repelled from the side of the can to the distance of about nine or ten inches. The can would not then receive another spark from the wire of the vial; but as I gradually drew up the chain, the atmosphere of the can diminish'd by flowing over the rising chain, and the lock of cotton accordingly drew nearer and nearer to the can; and then, if I again brought the vial wire near the can, it would receive another spark, and the cotton fly off again to its first distance; and thus, as the chain

was drawn higher, the can would receive more sparks; because the can and extended chain were capable of supporting a greater atmosphere than the can with the chain gather'd up into its belly.—And that the atmosphere round the can was diminished by raising the chain, and increased again by lowering it, is not only agreeable to reason, since the atmosphere of the chain must be drawn from that of the can, when it rose, and returned to it again when it fell; but was also evident to the eye, the lock of cotton always approaching the can when the chain was drawn up, and receding when it was let down again.

Thus we see that increase of surface makes a body capable of receiving a greater electric atmosphere: But this experiment does not, I own, fully demonstrate my new hypothesis; for the brass and silver still continue in their solid state, and are not rarified into vapour, as the water is in clouds. Perhaps some future experiments on vapourized water may set this matter in a clearer light.

One seemingly material objection arises to the new hypothesis, and it is this. If water, in its rarified state, as a cloud, requires, and will absorb more of the electric fluid than when in its dense state as water, why does it not acquire from the earth all it wants at the instant of its leaving the surface, while it is yet near, and but just rising in vapour? To this difficulty I own I cannot at present give a solution satisfactory to myself: I thought,
how-

however, that I ought to state it in its full force, as I have done, and submit the whole to examination.

And I would beg leave to recommend it to the curious in this branch of natural philosophy, to repeat with care and accurate observation, the experiments I have reported in this and former papers relating to *positive* and *negative* electricity, with such other relative ones as shall occur to them, that it may be certainly known whether the electricity communicated by a glass globe, be *really positive*. And also I would request all who may have an opportunity of observing the recent effects of lightning on buildings, trees, &c. that they would consider them particularly with a view to discover the direction. But in these examinations, this one thing is always to be understood, *viz.* that a stream of the electric fluid passing thro' wood, brick, metal, &c. while such fluid passes in *small quantity*, the mutually repulsive power of its parts is confined and overcome by the cohesion of the parts of the body it passes through, so as to prevent an explosion; but when the fluid comes in a quantity too great to be confin'd by such cohesion, it explodes, and rends or fuses the body that endeavour'd to confine it. If it be wood, brick, stone, or the like, the splinters will flie off on that side where there is least resistance. And thus, when a ~~whole~~ hole is struck thro' paste-board by the electrify'd jar, if the surfaces of the paste-board are not confin'd or compress'd, there will be a bur rais'd all round the hole on both sides the pasteboard; but if one side be confin'd, so that the bur cannot be rais'd on that side,

side, it will be all rais'd on the other, which way soever the fluid was directed. For the bur round the outside of the hole, is the effect of the explosion every way from the center of the stream, and not an effect of the direction.

In every stroke of lightning, I am of opinion that the stream of the electric fluid, moving to restore the equilibrium between the cloud and the earth, does always previously find its passage, and mark out, as I may say, its own course, taking in its way all the conductors it can find; such as metals, damp walls, moist wood, &c. and will go considerably out of a direct course, for the sake of the assistance of good conductors; and that, in this course, it is actually moving, tho' silently and imperceptibly, before the explosion, in and among the conductors; which explosion happens only when the conductors cannot discharge it as fast as they receive it, by reason of their being incompleat, disunited, too small, or not of the best materials for conducting. Metalline rods, therefore, of sufficient thickness, and extending from the highest part of an edifice to the ground, being of the best materials and compleat conductors, will, I think, secure the building from damage; either by restoring the equilibrium so fast as to prevent a stroke, or by conducting it in the substance of the rod as far as the rod goes, so that there shall be no explosion but what is above its point, between that and the clouds.

If it be ask'd, what thickness of a metalline rod may be suppos'd sufficient? In answer, I would remark, that five large glass jars, such as I have described in my former papers,

pers, discharge a very great quantity of electricity, which nevertheless will be all conducted round the corner of a book, by the fine filleting of gold on the cover, it following the gold the farthest way about, rather than take the shorter course through the cover, that not being so good a conductor. Now in this line of gold the metal is so extremely thin as to be little more than the colour of gold, and on an octavo book is not in the whole an inch square, and therefore not the 36th part of a grain according to M. *Reaumur*; yet 'tis sufficient to conduct the charge of 5 large jars, and how many more I know not. Now, I suppose a wire of $\frac{1}{4}$ inch diameter to contain about 5000 times as much metal as there is in that gold line, and if so, it will conduct the charge of 25,000 such glass jars, which is a quantity, I imagine, far beyond what was ever contain'd in any one stroke of natural lightning. But a rod of half an inch diameter would conduct four times as much as one of a quarter.

And with regard to conducting; tho' a certain thickness of metal be required to conduct a great quantity of electricity, and, at the same time, keep its own substance firm and unseparated; and a less quantity, as a very small wire for instance, will be destroy'd by the explosion; yet such small wire will have answer'd the end of conducting that stroke, tho' it become incapable of conducting another. And considering the extream rapidity with which the electric fluid moves without exploding, when it has a free passage, or compleat metal communication, I should think

think a vast quantity would be conducted in a short time, either to or from a cloud, to restore its equilibrium with the earth, by means of a very small wire ; and therefore thick rods should seem not so necessary.—However, as the quantity of lightning discharg'd in one stroke cannot well be measured, and, in different strokes, is certainly very various, in some much greater than others ; and as iron (the best metal for the purpose, being least apt to fuse) is cheap, it may be well enough to provide a larger canal to guide that impetuous blast, than we imagine necessary : For, though one middling wire may be sufficient, two or three can do no harm. And time, with careful observations well compar'd, will at length point out the proper size to greater certainty.

Pointed rods erected on edifices may likewise often prevent a stroke, in the following manner. An eye so situated as to view horizontally the under side of a thunder cloud, will see it very ragged, with a number of separate fragments, or petty clouds, one under another, the lowest sometimes not far from the earth. These, as so many stepping-stones, assist in conducting a stroke between the cloud and a building. To represent these by an experiment, take two or three locks of fine loose cotton, connect one of them with the prime conductor by a fine thread of two inches, (which may be spun out of the same lock by the fingers) another to that, and the third to the second, by like threads.—Turn the globe, and you will

will see these locks extend themselves towards the table, (as the lower small clouds do towards the earth) being attracted by it: But on presenting a sharp point erect under the lowest, it will shrink up to the second, the second to the first, and all together to the prime conductor, where they will continue as long as the point continues under them. May not, in like manner, the small electrified clouds, whose equilibrium with the earth is soon restor'd by the point, rise up to the main body, and by that means occasion so large a vacancy, as that the grand cloud cannot strike in that place?

These thoughts, my dear friend, are many of them crude and hasty; and if I were merely ambitious of acquiring some reputation in philosophy, I ought to keep them by me, till corrected and improved by time and farther experience. But since even short hints, and imperfect experiments in any new branch of science, being communicated, have oftentimes a good effect, in exciting the attention of the ingenious to the subject, and so become the occasion of more exact disquisitions, and more compleat discoveries. You are at liberty to communicate this paper to whom you please; it being of more importance that knowledge should increase, than that your friend should be thought an accurate philosopher.

LETTER XIII.

FROM

BENJAMIN FRANKLIN, *Esq*; at *Philadelphia*.

TO

PETER COLLINSON, *Esq*; F. R. S. at *London*.

S I R,

April 18, 1754.

SINCE *September* last, having been abroad on two long journeys, and otherwise much engag'd, I have made but few observations on the *positive* and *negative* state of electricity in the clouds. But Mr *Kinnersley* kept his rod and bells in good order, and has made many.

Once this winter the bells rang a long time, during a fall of snow, tho' no thunder was heard or lightning seen. Sometimes the flashes and cracks of the electric matter between bell and bell were so large and loud, as to be heard all over the house: but by all his observations, the clouds were constantly in a negative state, till about six weeks ago, when he found them once to change in a few minutes from the negative to the positive. About a fortnight

night after that he made another observation of the same kind; and last *Monday* afternoon, the wind blowing hard at S. E. and veering round to N. E. with many thick driving clouds, there were five or six successive changes from negative to positive, and from positive to negative, the bells stopping a minute or two between every change. Besides the methods mentioned in my paper of *September* last, of discovering the electrical state of the clouds, the following may be us'd. When your bells are ringing, pass a rubb'd tube by the edge of the bell, connected with your pointed rod: if the cloud is then in a negative state, the ringing will stop; if in a positive state, it will continue, and perhaps be quicker. Or, suspend a very small cork-ball by a fine silk thread, so that it may hang close to the edge of the rod-bell: then whenever the bell is electrified, whether positively or negatively, the little ball will be repell'd, and continue at some distance from the bell. Have ready a round-headed glass stopper of a decanter, rub it on your side 'till it is electrified, then present it to the cork-ball. If the electricity in the ball is positive, it will be repell'd from the glass stopper as well as from the bell. If negative, it will fly to the stopper.

R E M A R K S
On the Abbe NOLLET's
LETTERS ON ELECTRICITY.

T O
BENJ. FRANKLIN, *Esq*; of *Philadelphia*.

B Y
Mr DAVID COLDEN, of *New-York*,

S I R, Coldenham, in *N. York*, Dec. 4, 1753.

I N considering the Abbé *Nollet*'s letters to Mr *Franklin*, I am obliged to pass by all the experiments which are made with, or in, bottles hermetically sealed, or exhausted of air; because, not being able to repeat the experiments, I could not second any thing, which occurs to me thereon, by experimental proof. Wherefore, the first point wherein I can dare to give my opinion, is in the Abbe's 4th letter, *p*. 66, where he undertakes to prove, that the electric matter passes from one surface to another through the intire thickness of the glass: He takes Mr *Franklin*'s experiment of the magical picture, and writes thus of it. "When you electrify a pane of glass coated
on

“ on both sides with metal, it is evident that whatever is
“ placed on the side opposite to that which receives the
“ electricity from the conductor, receives also an evident
“ electrical virtue.” Which Mr *Franklin* says, is that equal quantity of electric matter, driven out of this side; by what is received from the conductor on the other side; and which will continue to give an electrical virtue, to any thing in contact with it, till it is entirely discharged of its electrical fire. To which the Abbé thus objects:
“ Tell me, says he, I pray you, how much time is necessary for this pretended discharge? I can assure you,
“ that after having maintain’d the electrification for hours,
“ this surface, which ought, as it seems to me, to be entirely discharged of its electrical matter, considering either the vast number of sparks that were drawn from it,
“ or the time that this matter had been exposed to the action
“ of the expulsive cause; this surface, I say, appeared rather better electrified thereby, and more proper to produce all the effects of an actual electric body.” p. 68.

The Abbé does not tell us what those effects were: all the effects I could never observe, and those that are to be observed can easily be accounted for, by supposing that side to be entirely destitute of electric matter. The most sensible effect of a body charged with electricity is, that when you present your finger to it, a spark will issue from it to your finger: Now when a phial, prepared for the *Leyden* experiment, is hung to the gun-barrel or prime-
con-

conductor, and you turn the globe in order to charge it; as soon as the electric matter is excited, you can observe a spark to issue from the external surface of the phial to your finger; which, Mr *Franklin* says, is the natural electric matter of the glass driven out by that received by the inner surface from the conductor. If it be only drawn out by sparks, a vast number of them may be drawn; but if you take hold of the external surface with your hand, the phial will soon receive all the electric matter it is capable of, and the outside will then be entirely destitute of its electric matter, and no spark can be drawn from it by the finger: here then is a want of that effect which all bodies, charged with electricity, have. Some of the effects of an electric body, which I suppose the Abbé has observed in the exterior surface of a charged phial, are that all light bodies are attracted by it. This is an effect which I have constantly observed, but do not think that it proceeds from an attractive quality in the exterior surface of the phial, but in those light bodies themselves, which seem to be attracted by the phial. It is a constant observation, that when one body has a greater charge of electric matter in it than another (that is in proportion to the quantity they will hold) this body will attract that which has less: Now, I suppose, and it is a part of Mr *Franklin's* system, that all those light bodies which appear to be attracted, have more electric matter in them than the external surface of the phial has, wherefore they endeavour to attract the
phial

phial to them, which is too heavy to be moved by the small degree of force they exert, and yet being greater than their own weight, moves them to the phial. The following experiment will help the imagination in conceiving this. Suspend a cork ball, or a feather by a silk thread and electrify it, then bring this ball nigh to any fixed body, and it will appear to be attracted by that body, for it will fly to it: Now, by the consent of electricians, the attractive cause is in the ball itself, and not in the fixed body to which it flies: This is a similar case with the apparent attraction of light bodies, to the external surface of a charged phial.

The Abbé says, *p.* 69. "that he can electrify a hundred men, standing on wax, if they hold hands, and if one of them touch one of these surfaces (the exterior) with the end of his finger": This I know he can, while the phial is charging, but after the phial is charged I am as certain he cannot: That is, hang a phial, prepared for the *Leyden* experiment, to the conductor, and let a man, standing on the floor, touch the coating with his finger, while the globe is turn'd, till the electric matter spews out of the hook of the phial, or some part of the conductor, which I take to be the certainest sign that the phial has received all the electric matter it can: after this appears, let the man, who before stood on the floor, step on a cake of wax, where he may stand for hours, and the globe all that time turned, and yet have no appearance of being electrified. Af-

ter

ter the electric matter was spewed out as above from the hook of a phial, prepared for the *Leyden* experiment, I hung another phial, in like manner prepared, to a hook fixed in the coating of the first, and held this other phial in my hand; now if there was any electric matter transmitted thro' the glass of the first phial, the second one would certainly receive and collect it; but having kept the phials in this situation for a considerable time, during which the globe was continually turned, I could not perceive that the second phial was in the least charged, for when I touched the hook with my finger, as in the *Leyden* experiment, I did not feel the least commotion, nor perceive any spark to issue from the hook.

I likewise made the following experiment. Having charged two phials (prepared for the *Leyden* experiment) through their hooks; two persons took each one of these phials in their hand, one held his phial by the coating, the other by the hook, which he could do by removing the communication from the bottom before he took hold of the hook. These persons placed themselves, one on each side of me, while I stood on a cake of wax, and took hold of the hook of that phial which was held by its coating (upon which a spark issued, but the phial was not discharged, as I stood on wax) keeping hold of the hook, I touched the coating of the phial that was held by its hook with my other hand; upon which there was a large spark to be seen between my finger and the coating, and both phials were instantly

instantly discharged. If the Abbé's opinion be right, that the exterior surface, communicating with the coating, is charged, as well as the interior, communicating with the hook; how can I, who stand on wax, discharge both these phials, when it is well known I could not discharge one of them singly? Nay, suppose I have drawn the electric matter from both of them, what becomes of it? For I appear to have no additional quantity in me when the experiment is over, and I have not stirr'd off the wax: Wherefore this experiment fully convinces me, that the exterior surface is not charged; and not only so, but that it wants as much electric matter as the inner has of excess: For by this supposition, which is a part of Mr *Franklin's* system, the above experiment is easily accounted for, as follows:



When I stand on wax, my body is not capable of receiving all the electric matter from the hook of one phial, which it is ready to give; neither can it give as much to the coating of the other phial as it is ready to take, when one is only

T

ap-

applied to me: But when both are applied, the coating takes from one what the hook gives: Thus I receive the fire from the first phial at B, the exterior surface of which is supplied from the hand at A: I give the fire to the second phial at C, whose interior surface is discharged by the hand at D. This discharge at D may be made evident by receiving that fire into the hook of a third phial, which is done thus: In place of taking the hook of the second phial in your hand, run the wire of a third phial, prepared as for the *Leyden* experiment, through it, and hold this third phial in your hand, the second one hanging to it, by the ends of the hooks run through each other: When the experiment is performed, this third phial receives the fire at D, and will be charged. When this experiment is considered, I think, it must fully prove that the exterior surface of a charged phial wants electric matter, while the inner surface has an excess of it. One thing more, worthy of notice in this experiment is, that I feel no commotion or shock in my arms, tho' so great a quantity of electric matter passes through them instantaneously: I only feel a prickling in the ends of my fingers. This makes me think the *Abbé* has mistook, when he says, that there is no difference between the shock felt in performing the *Leyden* experiment, and the prickling felt on drawing simple sparks, except that of greater to less. In the last experiment, as much electric matter went through my arms, as would have given me a very sensible shock, had there been an immediate com-

mu-

munication, by my arms; from the hook to the coating of the same phial; because when it was taken into a third phial, and that phial discharged singly thro' my arms, it gave me a sensible shock. If these experiments prove that the electric matter does not pass through the intire thickness of the glass; it is a necessary consequence that it must always come out where it enter'd.

The next thing I meet with, is in the Abbé's fifth letter p. 88, where he differs from Mr *Franklin*, who thinks that the whole power of giving a shock is in the glass itself, and not in the non-electrics^s in contact with it. The experiments which Mr *Franklin* gave to prove this opinion in his *Experiments and Observations on Electricity*, Letter III. p. 24. convinced me that he was in the right; and what the Abbé has asserted in contradiction thereto, has not made me think otherwise. The Abbé perceiving, as I suppose, that the experiments, as Mr *Franklin* had perform'd them, must prove his assertion; alters them without giving any reason for it, and makes them in a manner that proves nothing. Why will he have the phial, into which the water is to be decanted from a charged phial, held in a man's hand? If the power of giving a shock is in the water contain'd in the phial, it should remain there tho' decanted into another phial, since no non-electric body touch'd it to take that power off. The phial being placed on wax is no objection, for it cannot take the power from the water, if it had any, but it is a necessary

means to try the fact; whereas, that phial's being charged when held in a man's hand, only proves that water will conduct the electric matter. The *Abbé* owns, *p.* 94. that he had heard this remarked, but says, Why is not a conductor of electricity an electric subject? This is not the question; Mr *Franklin* never said that water was not an electric subject; he said, that the power of giving a shock was in the glass, and not in the water; and this, his experiments, fully prove; so fully, that it may appear impertinent to offer any more: Yet as I do not know that the following has been taken notice of by any body before, my inserting of it in this place may be excused. It is this: Hang a phial, prepared for the *Leyden* experiment, to the conductor, by its hook, and charge it, which done, remove the communication from the bottom of the phial. Now the conductor shews evident signs of being electrified; for if a thread be tied round it, and its ends left about two inches long, they will extend themselves out like a pair of horns; but if you touch the conductor, a spark will issue from it, and the threads will fall, nor does the conductor shew the least sign of being electrified after this is done. I think that by this touch, I have taken out all the charge of electric matter that was in the conductor, the hook of the phial, and water or filings of iron contain'd in it; which is no more than we see all non-electric bodies will receive; yet the glass of the phial retains its power of giving a shock, as any one will find

find that pleases to try. This experiment fully evidences, that the water in the phial contains no more electric matter than it would do in an open basin, and has not any of that great quantity which produces the shock, and is only retain'd by the glass. If after the spark is drawn from the conductor, you touch the coating of the phial (which all this while is supposed to hang in the air, free from any non-electric body) the threads on the conductor will instantly start up, and shew that the conductor is electrified. It receives this electrification from the inner surface of the phial, which, when the outer surface can receive what it wants from the hand applied to it, will give as much as the bodies in contact with it can receive, or, if they be large enough, all that it has of excess. It is diverting to see how the threads will rise and fall by touching the coating and conductor of the phial alternately. May it not be that the difference between the charged side of the glass, and the outer or emptied side, being lessen'd by touching the hook or the conductor; the outer side can receive from the hand which touched it, and by its receiving the inner side cannot retain so much; and for that reason so much as it cannot retain electrifies the water, or filings and conductor: For it seems to be a rule, that the one side must be emptied in the same proportion that the other is fill'd: Tho' this from experiment appears evident, yet it is still a mystery not to be accounted for.

I am

I am, in many places of the Abbé's book, surpris'd to find that experiments have succeeded so differently at *Paris* from what they did with Mr *Franklin*, and as I have always observ'd them to do. The Abbé, in making experiments to find the difference between the two surfaces of a charged glass, will not have the phial placed on wax: For, says he, don't you know that being placed on a body originally electric, it quickly loses its virtue? I cannot imagine what should have made the Abbé think so; it certainly is contradictory to the notions commonly received of electrics per se; and by experiment I find it entirely otherwise: For having several times left a charged phial, for that purpose, standing on wax for hours, I found it to retain as much of its charge as another that stood at the same time on a table. I left one standing on wax from 10 o'clock at night till 8 next morning, when I found it to retain a sufficient quantity of its charge, to give me a sensible commotion in my arms, though the room in which the phial stood had been swept in that time, which must have rais'd much dust to facilitate the discharge of the phial.

I find that a cork ball suspended between two bottles, the one fully and the other but little charged, will not play between them, but is driven into a situation that makes a triangle with the hooks of the phials; though the Abbé has asserted the contrary of this, *p.* 101, in order to account for the playing of a cork ball between the
wire

wire thrust into the phial, and one that rises up from its coating. The phial which is least charged must have more electric matter given to it, in proportion to its bulk, than the cork ball receives from the hook of the full phial.

The Abbé says, *p.* 103, “that a piece of metal leaf “hung to a silk thread and electrified, will be repell’d by “the bottom of a charged phial held by its hook in the “air;” This I find constantly otherwise, it is with me always first attracted and then repelled: It is necessary in charging the leaf to be careful that it does not fly off to some non-electric body, and so discharge itself when you think it is charged; it is difficult to keep it from flying to your own wrist, or to some part of your body.

The Abbé, *p.* 108, says, “that it is not impossible, as “Mr *Franklin* says it is, to charge a phial while there is a “communication form’d between its coating and its hook”. I have always found it impossible to charge such a phial so as to give a shock: Indeed if it hang on the conductor without a communication from it, you may draw a spark from it as you may from any body that hangs there, but this is very different from being charged in such a manner as to give a shock. The Abbé, in order to account for the little quantity of electric matter that is to be found in the phial, says, “that it rather follows the metal than the “glass, and that it is spewed out into the air from the coating “of the phial”. I wonder how it comes not to do so too,
when

when it sifts through the glass and charges the exterior surface, according to the Abbé's system!

The Abbé's objections against Mr *Franklin*'s two last experiments, I think, have little weight in them: He seems, indeed, much at a loss what to say, wherefore he taxes Mr *Franklin* with having conceal'd a material part of the experiment; a thing too mean for any gentleman to be charged with, who has not shewn as great a partiality in relating experiments, as the Abbé has done.



ELECTRICAL EXPERIMENTS,

With an Attempt to account for their

SEVERAL PHÆNOMENA;

Together with

Some Observations on *Thunder-Clouds*,

By *JOHN CANTON*, M. A. and F. R. S.

From the *Philosophical Transactions*.

Dec. 6, 1753.

EXPERIMENT I.

FROM the cieling, or any convenient part of a room, let two cork-balls, each about the bigness of a small pea, be suspended by linen threads of eight or nine inches in length, so as to be in contact with each other. Bring the excited glass tube under the balls,
U and

and they will be separated by it, when held at the distance of three or four feet; let it be brought nearer, and they will stand farther apart; intirely withdraw it, and they will immediately come together. This experiment may be made with very small brass balls hung by silver wire; and will succeed as well with sealing-wax made electrical, as with glafs.

E X P E R I M E N T III

If two cork-balls be suspended by dry silk threads, the excited tube must be brought within eighteen inches before they will repel each other; which they will continue to do, for some time, after the tube is taken away.

As the balls in the first experiment are not insulated, they cannot properly be said to be electrified: but when they hang within the atmosphere of the excited tube, they may attract and condense the electrical fluid round about them, and be separated by the repulsion of its particles. It is conjectur'd also, that the balls at this time contain less than their common share of the electrical fluid, on account of the repelling power of that which surrounds them; tho' some, perhaps, is continually entering and passing thro' the threads. And if that be the case, the reason is plain, why the balls hung by silk, in the second experiment, must be in a much more dense part of the atmosphere of the tube, before they will repel each other. At the approach of an excited stick of wax to the balls, in the first experiment, the electrical fire is supposed to
come

come through the threads into the balls, and be condensed there, in its passage towards the wax: for, according to Mr *Franklin*, excited glass *emits* the electrical fluid, but excited wax *receives* it.

EXPERIMENT III.

Let a tin tube, of four or five feet in length, and about two inches in diameter, be insulated by silk; and from one end of it let the cork-balls be suspended by linen threads. Electrify it, by bringing the excited glass tube near the other end, so as that the balls may stand an inch and an half, or two inches apart: then, at the approach of the excited tube, they will by degrees lose their repelling power, and come into contact; and as the tube is brought still nearer, they will separate again to as great a distance as before: in the return of the tube they will approach each other till they touch, and then repel as at first. If the tin-tube be electrified by wax, or the wire of a charged phial, the balls will be affected in the same manner at the approach of excited wax, or the wire of the phial.

EXPERIMENT IV.

Electrify the cork-balls as in the last experiment by glass; and at the approach of an excited stick of wax their repulsion will be increased. The effect will be the same, if the excited glass be brought towards them, when they have been electrified by wax.

The bringing the excited glass to the end, or edge of

the tin-tube, in the third experiment, is suppos'd to electrify it positively, or to add to the electrical fire it before contained ; and therefore some will be running off through the balls, and they will repel each other. But at the approach of excited glass, which likewise *emits* the electrical fluid, the discharge of it from the balls will be diminish'd ; or part will be driven back, by a force acting in a contrary direction ; and they will come nearer together. If the tube be held at such a distance from the balls, that the excess of the density of the fluid round about them, above the common quantity in air, be equal to the excess of the density of that within them, above the common quantity contain'd in cork ; their repulsion will be quite destroy'd. But if the tube be brought nearer ; the fluid without, being more dense than that within the balls, it will be attracted by them, and they will recede from each other again.

When the apparatus has lost part of its natural share of this fluid, by the approach of excited wax to one end of it, or is electrified negatively ; the electrical fire is attracted and imbib'd by the balls to supply the deficiency ; and that more plentifully at the approach of excited glass, or a body positively electrified, than before ; whence the distance between the balls will be increased, as the fluid surrounding them is augmented. And in general, whether by the approach or recess of any body ; if the difference between the density of the internal and external fluid
be

be increased, or diminished; the repulsion of the balls will be increased, or diminished, accordingly.

E X P E R I M E N T V.

When the insulated tin tube is not electrified, bring the excited glass tube towards the middle of it, so as to be nearly at right angles with it, and the balls at the end will repel each other; and the more so, as the excited tube is brought nearer. When it has been held a few seconds, at the distance of about six inches, withdraw it, and the balls will approach each other till they touch; and then separating again, as the tube is moved farther off, will continue to repel when it is taken quite away. And this repulsion between the balls will be increased by the approach of excited glass, but diminished by excited wax; just as if the apparatus had been electrified by wax, after the manner described in the third experiment.

E X P E R I M E N T VI.

Insulate two tin tubes, distinguished by *A* and *B*, so as to be in a line with each other, and about half an inch apart; and at the remote end of each, let a pair of cork balls be suspended. Towards the middle of *A*, bring the excited glass tube; and holding it a short time, at the distance of a few inches, each pair of balls will be observed to separate: withdraw the tube, and the balls of *A* will come together, and then repel each other again; but those of *B* will hardly be affected. By the approach of the excited

cited glass tube, held under the balls of *A*, their repulsion will be increased: but if the tube be brought, in the same manner, towards the balls of *B*, their repulsion will be diminished.

In the fifth experiment, the common stock of electrical matter in the tin tube, is supposed to be attenuated about the middle, and to be condensed at the ends, by the repelling power of the atmosphere of the excited glass tube, when held near it. And perhaps the tin tube may lose some of its natural quantity of the electrical fluid, before it receives any from the glass; as that fluid will more readily run off from the ends or edges of it, than enter at the middle: and accordingly, when the glass tube is withdrawn, and the fluid is again equally diffused through the apparatus, it is found to be electrified negatively: For excited glass brought under the balls will increase their repulsion.

In the sixth experiment, part of the fluid driven out of one tin tube enters the other; which is found to be electrified positively, by the decreasing of the repulsion of its balls, at the approach of excited glass.

EXPERIMENT VII.

Let the tin tube, with a pair of balls at one end, be placed three feet at least from any part of the room, and the air render'd very dry by means of a fire: electrify the apparatus to a considerable degree; then touch the tin tube with a finger, or any other conductor, and the balls will,

will, notwithstanding, continue to repel each other; tho' not at so great a distance as before.

The air surrounding the apparatus to the distance of two or three feet, is supposed to contain more or less of the electrical fire, than its common share, as the tin tube is electrified positively, or negatively; and when very dry, may not part with its overplus, or have its deficiency supplied so suddenly, as the tin; but may continue to be electrified, after that has been touch'd for a considerable time.

E X P E R I M E N T VIII.

Having made the Torricellian vacuum about five feet long, after the manner described in the *Philosophical Transactions*, Vol. xlvii. p. 370. if the excited tube be brought within a small distance of it, a light will be seen through more than half its length: which soon vanishes, if the tube be not brought nearer; but will appear again, as that is moved farther off. This may be repeated several times, without exciting the tube afresh.

This experiment may be consider'd as a kind of ocular demonstration of the truth of Mr. *Franklin's* hypothesis; that when the electrical fluid is condensed on one side of thin glass, it will be repelled from the other, if it meets with no resistance. According to which, at the approach of the excited tube, the fire is supposed to be repelled from the inside of the glass surrounding the vacuum, and to be carried

carried off through the columns of mercury; but, as the tube is withdrawn, the fire is supposed to return.

EXPERIMENT IX.

Let an excited stick of wax, of two feet and an half in length, and about an inch in diameter, be held near its middle. Excite the glass tube, and draw it over one half of it; then, turning it a little about its axis, let the tube be excited again, and drawn over the same half; and let this operation be repeated several times: then will that half destroy the repelling power of balls electrified by glass, and the other half will increase it.

By this experiment it appears, that wax also may be electrified positively and negatively. And it is probable, that all bodies whatsoever may have the quantity they contain of the electrical fluid, increased, or diminished. The clouds, I have observed, by a great number of experiments, to be some in a positive, and others in a negative state of electricity. For the cork balls, electrified by them, will sometimes close at the approach of excited glass; and at other times be separated to a greater distance. And this change I have known to happen five or six times in less than half an hour; the balls coming together each time, and remaining in contact a few seconds, before they repel each other again. It may likewise easily be discover'd, by a charged phial, whether the electrical fire be drawn out of the apparatus by a negative cloud, or forced into it by
a posi-

a positive one : and by whichsoever it be electrified, should that cloud either part with its overplus, or have its deficiency supplied suddenly, the apparatus will lose its electricity : which is frequently observed to be the case, immediately after a flash of lightning. Yet when the air is very dry, the apparatus will continue to be electrified for ten minutes, or a quarter of an hour, after the clouds have passed the zenith ; and sometimes till they appear more than half-way towards the horizon. Rain, especially when the drops are large, generally brings down the electrical fire : and hail, in summer, I believe never fails. When the apparatus was last electrified, it was by the fall of thawing snow ; which happened so lately, as on the 12th of *November* ; that being the twenty-sixth day, and sixty-first time, it has been electrified, since it was first set up ; which was about the middle of *May*. And as *Fahrenheit's* thermometer was but seven degrees above freezing, it is supposed the winter will not intirely put a stop to observations of this sort. At *London*, no more than two thunderstorms have happened during the whole summer : and the apparatus was sometimes so strongly electrified in one of them, that the bells, which have been frequently rung by the clouds, so loud as to be heard in every room of the house (the doors being open), were silenced by the almost constant stream of dense electrical fire, between each bell and the brass ball, which would not suffer it to strike.

I shall conclude this paper, already too long, with the following queries :

1. May not air, suddenly rarefied, give electrical fire to, and air suddenly condensed, receive electrical fire from, clouds and vapours passing through it?

2. Is not the *aurora borealis*, the flashing of electrical fire from positive, towards negative clouds at a great distance, through the upper part of the atmosphere, where the resistance is least?



A P P E N D I X.

AS Mr *Franklin*, in a former letter to Mr *Collinson*, mentioned his intending to try the power of a very strong electrical shock upon a turkey, that gentleman accordingly has been so very obliging as to send an account of it, which is to the following purpose.

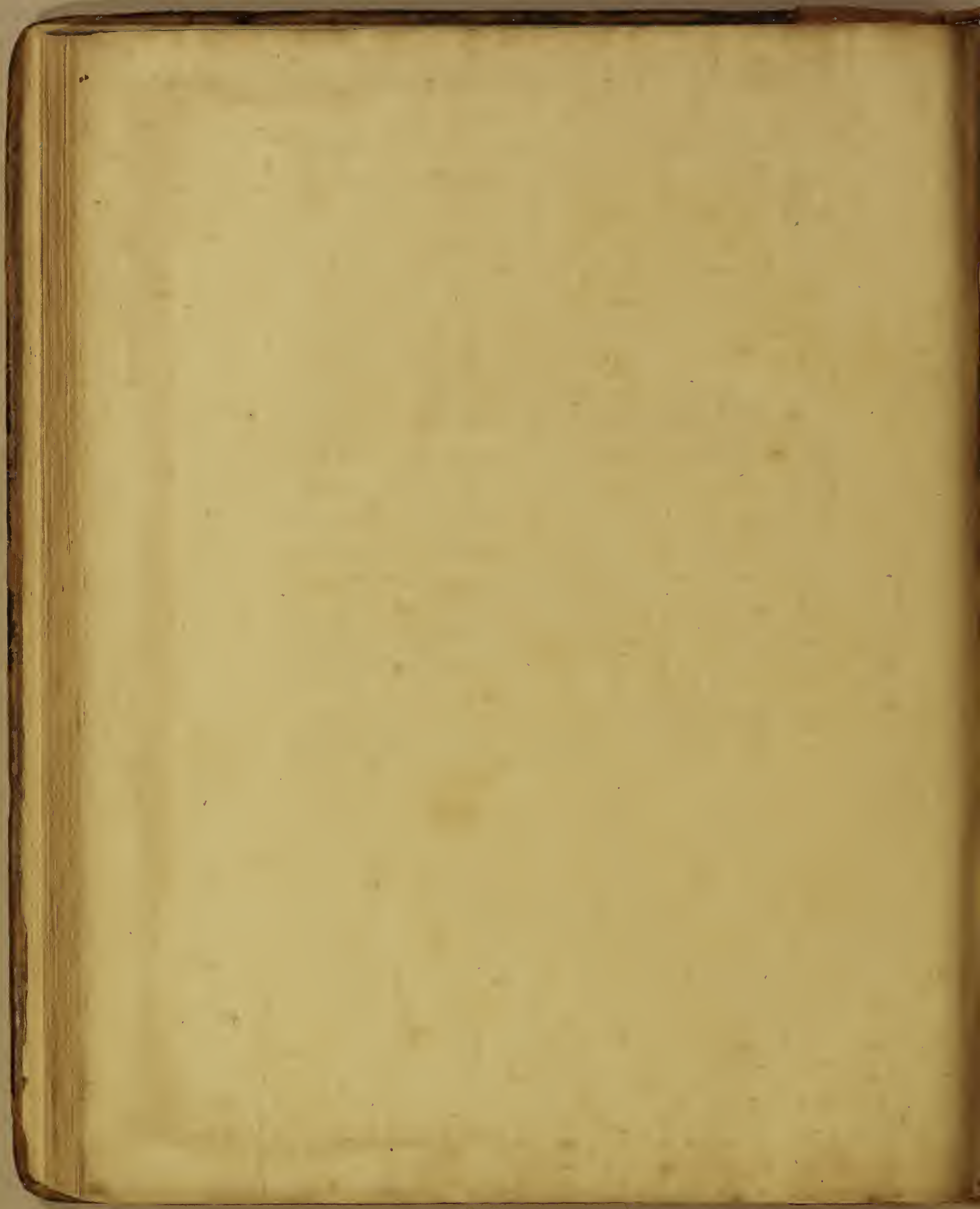
He made first several experiments on fowls, and found, that two large thin glass jars gilt, holding each about six gallons, and such as I mentioned I had employed in the last paper I laid before you on this subject, were sufficient, when fully charged, to kill common hens outright; but the turkeys, though thrown into violent convulsions, and then, lying as dead for some minutes, would recover in less than a quarter of an hour. However, having added three other such to the former two, though not fully charged, he killed a turkey of about ten pounds weight, and believes that they would have killed a much larger. He conceited, as himself says, that the birds kill'd in this manner eat uncommonly tender.

In making these experiments, he found, that a man could, without great detriment, bear a much greater shock than he imagined: for he inadvertently received the stroke of two of these jars through his arms and body, when they were very near fully charged. It seemed to him an universal blow throughout the body from head to foot,
and

and was followed by a violent quick trembling in the trunk, which went off gradually in a few seconds. It was some minutes before he could recollect his thoughts, so as to know what was the matter; for he did not see the flash, tho' his eye was on the spot of the prime conductor, from whence it struck the back of his hand; nor did he hear the crack, though the by-standers said it was a loud one; nor did he particularly feel the stroke on his hand, tho' he afterwards found it had raised a swelling there, of the bigness of half a swan-shot, or pistol-bullet. His arms and the back of his neck felt somewhat numbed the remainder of the evening, and his breast was sore for a week after, as if it had been bruised. From this experiment may be seen the danger, even under the greatest caution, to the operator, when making these experiments with large jars; for it is not to be doubted, but several of these fully charged would as certainly, by increasing them, in proportion to the size, kill a man, as they before did a turkey.

N. B. The original of this letter, which was read at the Royal Society, has been mislaid.

F I N I S.



Sept 23/55

Lc

D754
F831n

20874

